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# DREDGED MATERIAL RESEARCH PROGRAM

U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

## TECHNICAL REPORT D-77-28

# UNDERGROUND BIOMASS DYNAMICS AND SUBSTRATE SELECTIVE PROPERTIES OF ATLANTIC COASTAL SALT MARSH PLANTS

by

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The University of Georgia Marine Institute
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Final Report

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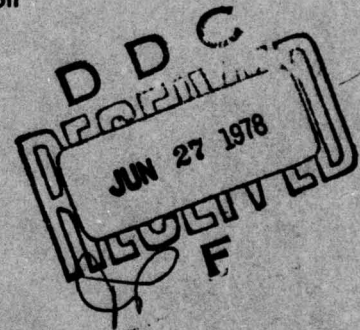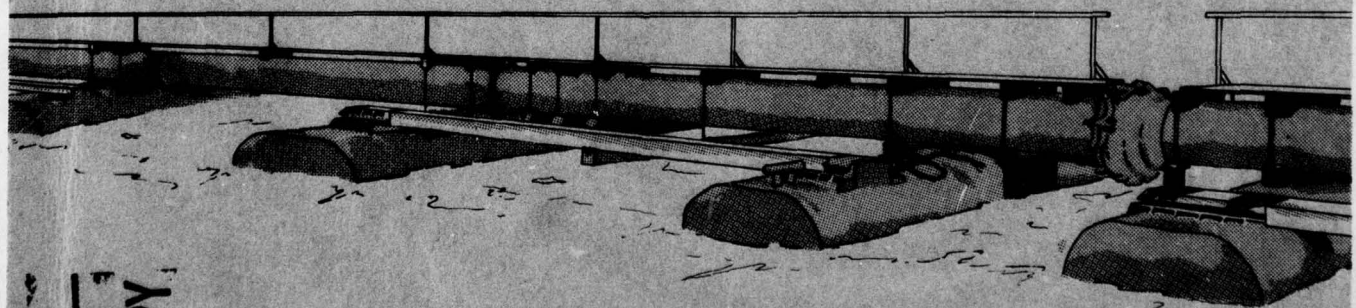VICKSBURG. MISSISSIPPI 39180

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1. The technical report transmitted herewith represents the results of one of the research efforts (work units) under Task 4A (Marsh Development) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 4A is a part of the Habitat Development Project of the DMRP and is concerned with developing, testing, and evaluating the environmental, economic, and engineering feasibility of using dredged material as a substrate for marsh development.

2. An intensive study of the underground portion of selected salt marsh species was conducted under Work Unit 4A04A2. The purpose of this research was to describe the characteristics of natural marsh substrates and to define the interactions between marsh plant growth and each characteristic of the substrate. The most useful combination of parameters for predicting marsh plant success was found to be soil texture, pH, salinity, and total nitrogen. Criteria for determining when the soil conditions in a man-made marsh approximate those of natural marshes have also been included in this report.

3. This work unit is one of several research efforts designed by the DMRP to document marsh productivity and the factors which influence that productivity. Closely related work units are 4A04A1 and 4A04B, which address the productivity of minor marsh species along the Atlantic and Gulf coasts, respectively; 4A04, in which a simulation model to predict salt marsh productivity was developed; and 4A20, a less intensive effort that will provide a general evaluation of salt marsh productivity on the Pacific coast of the United States. Additional supportive and comparative data will be forthcoming with the final analysis of the results of field studies at Windmill Point, Virginia, (4A11); Buttermilk Sound, Georgia, (4A12); Apalachicola, Florida, (4A19); Bolivar Peninsula, Texas, (4A13); Pond No. 3, California, (4A18); and Miller Sands, Oregon, (4B05).

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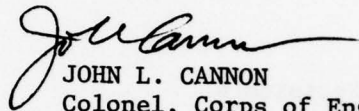Together these research products provide the Corps with a comprehensive
basis for sound management decisions regarding habitat development on
dredged material and disposal in natural marsh habitats.


JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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Atlantic Coast        Marsh plants
Biomass               Salt marshes
Dredged material      Substrates

An intensive study was made

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of the U. S. Army Corps of Engineers' comprehensive Dredged Material Research Program, which is being conducted by the Environmental Effects Laboratory of the U. S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi, an intensive study of the dynamics of the underground portion of selected salt marsh plants along the U. S. Atlantic Coast was made. The plants studied included: Borrichia frutescens, Carex paleacea, Distichlis spicata, Eleocharis obtusa, Juncus gerardi J. roemerianus, Phragmites communis,

(Continued)

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20. ABSTRACT (Continued).

Salicornia virginica, Spartina alterniflora, S. bakeri, S. cynosuroides, S. patens, and Sporobolus virginicus.

The study provides information applicable to marsh development on dredged material, particularly methodologies that can be used for determining which marsh plants will be likely to do well on various kinds of dredged material and when a marsh, which has been established on dredged material, approaches natural conditions.

The overall study focuses on three major efforts: an investigation of underground biomass dynamics, characterization of soils supporting the salt marsh plants; and experimentation on the substrate selective properties of several of the marsh plants studied. The methods and results for the specific aspects of these three efforts are delineated in five self-contained sections of the report: underground biomass profiles and dynamics in Atlantic coastal marshes; comparison of some tidal marsh soils along the Atlantic Coast, response of salt marsh plant stands to a pulse of ammonium nitrate; salt marsh plant growth on three types of dredged material; and a bioassay approach to studying marsh plant root growth in natural soil and dredged material.

*The following topics are included:* (handwritten margin note)

Findings of the studies indicate that in developing salt marsh on dredged material, five substrate problems should be considered: stability (dredged material texture and exposure to wave action); pH characteristics (pH in situ, in water, and in buffer); salinity characteristics (in situ, leacheable, desalination index); soil characteristics; and nutrients, of which nitrogen appears to be the key element. Depth of root penetration must also be considered when dredged material containing contaminants is used.

The report gives recommendations on the use of dredged material and plant species and emphasizes the advisability of a field bioassay prior to dredging. While it is not yet possible to predict with high probability the success of a specific plant on a specific dredged material in a specific salinity and under a specific tidal regime, the report shows that the most useful combinations of parameters in predicting marsh plant success are: soil texture, pH properties, salinity, and total nitrogen.

The appendixes were prepared on microfiche and are enclosed in an envelope in the back cover.

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# EXECUTIVE SUMMARY

This report summarizes work done on the dynamics of the underground portion of some of the salt marsh plants along the Atlantic coast of the United States, the characterization of soils in those plant stands, and experiments on the substrate selective properties of several of the plants.

The underground biomass profiles and dynamics study (Part II) involved year-long sampling programs in 18 stands of salt marsh plants in Georgia, Delaware, and Maine.  Cores of the marsh were taken at monthly or bimonthly intervals and the cores sectioned into depth profiles (0-5 cm, 5-10 cm, 10-15 cm, 15-35 cm, and 35-55 cm for some plants) and the macro-organic matter (MOM - organic matter not passing a 1-mm sieve) separated by washing on a 1-mm sieve.  THe MOM was dried and profiles and seasonal curves plotted from these data.  Three types of profiles were found in the marshes.  In the first the concentration of MOM was uniform with depth; the notable example of this type was creekbank <u>Spartina</u> <u>alterniflora</u> in the southern part of the coast.  A second type had a high concentration at the surface which dropped with depth.  Most species exhibited this type of profile.  <u>Spartina</u> <u>patens</u>, <u>S</u>. <u>alterniflora</u> from the high marsh along the southern coast, and creekbank <u>S</u>. <u>alterniflora</u> from the northern range (Maine) are examples. The third type was seen where a large rhizome mat developed at 15-20 cm below the surface.  This type of profile had a relatively low biomass at the surface, a higher biomass somewhat below the surface, and

a low concentration below that. Spartina cynosuroides and Phragmites communis were typical examples. The information on the types of profiles present in the natural marsh will be useful in determining when the natural profile shapes and MOM concentrations have been achieved in marshes formed on dredged material. Since the underground MOM is important in stabilizing the dredged material, supplying microbes with organic and inorganic nutrients, and thus regulating nutrient exchange between the soil and the overlying water, achievement of the "natural situation" is of prime importance in marsh-creation projects.

The annual highs and lows of MOM biomass were used to calculate an annual increment, which can be considered a minimum annual production value. The values ranged from a low of 80 g C/m$^2$ for creekhead S. alterniflora in Maine to a high of 1690 g C/m$^2$ for Juncus gerardi in Maine. The mean for all stands measured was 654 g C/m$^2$. Since the average carbon content of the MOM was 35.3%, this corresponds to 1852 g dry weight/m$^2$ per year which is comparable to the usually reported aerial production for marsh macrophytes. The plants are therefore allocating a major portion of the photosynthate to the underground portion of the plant and the food web dominated by meiobenthic animals and soil microbes. The latter group is particularly important in determining the cycling concentrates in the water flowing over marshes.

As a measure of the relative activity of the total pool of macro-organic material in the soil, a turnover time was calculated by dividing the total macro-organic matter by the annual increment. While there are at least several pools with turnover times varying from days

to centuries, the overall turnover gives a measure which can be used to estimate production when the quantity of macro-organic matter is known but there is no time for a yearlong study. The turnover time ranged from 18 months in two Georgia plant stands to 224 months for one in Maine. In the two instances where Maine values for a species could be compared to those from Georgia, the turnover time was less for the more southerly station. This probably reflected the slower microbial decay rates in the cooler climate. Thus most elements are bound to large particles of organic matter in the lower temperature climate. In Georgia and Maine where the turnover values for a single species were determined for two elevations, the time was less for the lower elevation. This probably resulted from greater microbial activity associated with more rapid flushing rates of water through the creekbank soils. The mineral composition of the underground portions of the plants is presented in Part II and Appendix B. This information can be used to determine if a planted marsh has the same elemental composition as a natural one.

Part III of the report describes soil profiles in plant stands in marshes in Georgia, Delaware, and Maine. These descriptions give data which are useful in classifying soils associated with various marsh plants along the Atlantic coast and would be useful in evaluating to what extent a marsh developed on dredged material resembles a natural marsh.

In addition to the field descriptions, data are presented which describe the physical and chemical aspects of the various horizons.

The most important of these for predicting the success    dredged
material would have in supporting a given plant are the salinity
characteristics (salinity, desalination index), pH properties (pH in
situ, pH in water, and pH in buffer), and total nitrogen (N) which
can be obtained either directly or by correlation with C content.
Also presented are data on leachable ions.  These ionic data were
obtained on dried soils rather than those kept moist and under
anaerobic conditions.  This was done although the anaerobic moist
condition represents the natural condition under which these soils
exist.  The authors feel that the extractions under any conditions
do not represent the actual conditions to which roots are exposed.
Because roots are continually removing nutrients, the flux rate rather
than the pool size measured by extraction is the most important factor
to consider.  Additionally, no chemical extraction can duplicate the
roots' capability to remove nutrients.  Further, it is doubted that
District Engineers would have facilities to take and ship soil samples
under anaerobic conditions and have labs available to analyze them
under those conditions; therefore, the soils were handled as typically
done by agriculture researchers.  District Engineers will be able to
handle dredged material in this fashion and have it analyzed in local
state college agricultural experiment stations.  The success agricul-
ture researchers have had in predicting yields and making recommen-
dations regarding species success and advising fertilizer and lime
requirements has been based on correlations between soils tests and
field experiences rather than absolute tidal concentration of

nutrients. In this study, data collection was begun for eventual
prediction capability. The data represent natural soils and three
widely differing types of dredged material from Georgia.

Part IV reports on the response of marsh plant stands to a pulse
of nitrogen. In Georgia, Salicornia virginica and S. alterniflora
responded to a 150 kg/ha pulse of N (as $NH_4NO_3$) by an increase in bio-
mass. Although no biomass change was noted, the Sporobolus virginicus
plants were higher in nitrogen than the control plants. Borrichia
frutescens had a higher chlorophyll concentration, although no other
response was detected in stands of Distichlis spicata, S. cynosuroides,
or S. patens. In Delaware a positive biomass response was obtained in
stands of J. gerardi and S. virginica. Although no biomass differences
were measured, the treated D. spicata plants were significantly higher
in chlorophyll than were the control plants. None of the plant stands
in Maine responded to added N. This might be expected in view of the
high levels of extractable $NH_4$ found in the soil (Part III). No dif-
ferences in ability to remove N from various application depths to
35 cm were noted.

Part V of this report deals with tests of marsh plant growth on
three types of dredged material in the greenhouse and in field test
sites. Specific recommendations regarding the growth of species or sub-
strates tested are given in this section. The synthesis of this and the
previous section is that it is not possible with the present state of
knowledge to predict with high probability the success of a specific plant
on a specific dredged material in a specific salinity and in a specific

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tidal inundation regime. Therefore, a bioassay is proposed to be made by District Engineers using a series of modified buckets to check plant performance at specific sites prior to attempting marsh establishment on dredged material.

Part VI deals with bioassay techniques designed to assess root growth in specific dredged material. The method is presented as are specific results of several experiments. In a test with a freshwater plant (Eleocharis obtusa), the best growth was in a sandy dredged material of low salinity. Approximately 1/3 as much growth occurred in two freshwater muds. Growth in a saline sand, a saline silty clay, and a brackish mixture of sand and silty clay produced only 1/7 the growth obtained with low salinity sand.

Spartina patens root growth is enhanced when whole plants are grown under cooler rather than warmer environmental conditions. Spartina patens and S. alterniflora root growth did not differ under drained or saturated conditions when a sand substrate was used. Equal growth was obtained with either 10 or 20‰ salinity. Growth in natural soil was 6-12 times greater than in the sandy saline dredged material tested. When the soil temperature was lowered while air temperature remained high, three species of Spartina (S. alterniflora, S. bakeri, and S. patens) showed reduced aerial and underground growth. This indicates the increased root growth at low temperatures seen in two earlier experiments where whole plants were subjected to the temperature differences was either a whole plant effect or an effect on the shoots alone.

In drawing conclusions and recommendations from these studies, there appear to be five substrate problems which should be considered when planning to create a salt marsh.

1. Stability. Two factors are important here: exposure to wave action and dredged material texture. Although this problem was not addressed directly in this study, some of the results are pertinent. The development of a large root underground system (roots and rhizome) is important. Particularly effective in this respect are S. patens, D. spicata, and S. virginicus.

2. pH characteristics. Basic to this problem is the cat clay characteristic of soils containing sulfides. In this situation, reduced forms of sulfur oxidize when the sediment is exposed to air and the resulting strong acid causes a sharp drop in pH. Examination of pH in situ, pH after drying, and pH in buffer can be used to predict the probable extent of cat clay development.

3. Salinity characteristics. Coupled with salinity tolerance is drought tolerance. In salt marshes, drought conditions are almost always coupled with high salinity situations. If dredged material is placed in subtidal areas, the drought and salinity conditions can be regulated by the final elevations of the created island. In cases where dredged material is placed on existing marsh, salinity and drought conditions will often be accentuated because of the high elevation. The plants found to be most tolerant of these conditions are S. patens, D. spicata, S. virginicus, and S. virginica.

4. Elevation (balance of air and water). The elevation factor is complex, involving salinity and pH characteristics as well as other factors. Since dredged material placed low in the intertidal range will be inundated more frequently and for longer periods than that placed near the upper boundary of the tides' influence, different soil characteristics will develop along the gradient. Soil pH will usually be lower in the upper zone because of oxidation of sulfur forms in the better drained soils. The pH drop may be dramatic and prevent plant growth with certain collections of sulfur ion species. Salinity will be more stable where tidal water frequently flushes the soil. In the upper reaches, evapotranspiration will tend to concentrate salt and fluctuations will be too great for many species to tolerate. Soil structure may also be influenced

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by salt accumulation resulting in the reduced percolation of rainwater. The authors believe the best evaluation of this complex factor can be made by a bioassay on the site.

5. <u>Nutrients</u>. As with many ecosystems, N seems to be a key element. Only in sandy dredged material does it seem probable that N will be the limiting factor to the growth of the plants.

When dredged material containing contaminants such as heavy metals and pesticides is used for marsh development, the depth to which roots penetrate the substrate must be considered. The studies reported herein show that <u>S</u>. <u>virginica</u> and <u>S</u>. <u>virginicus</u> are shallow-rooted plants (< 35 cm); <u>S</u>. <u>alterniflora</u> at high elevations, <u>D</u>. <u>spicata</u>, and <u>S</u>. <u>patens</u> are medium in rooting depth (35-55 cm); and <u>S</u>. <u>alterniflora</u> plants at low elevations, <u>J</u>. <u>roemerianus</u>, and <u>P</u>. <u>communis</u> are deep-rooted (> 55 cm).

## PREFACE

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\* Appendixes A-C are reproduced on microfiche and are enclosed in an
envelope attached to the inside of the back cover.

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TABLES, Continued

TABLES, Continued

# UNDERGROUND BIOMASS DYNAMICS AND SUBSTRATE SELECTIVE

## PROPERTIES OF ATLANTIC COASTAL SALT MARSH PLANTS

### PART I:  INTRODUCTION

Among the important considerations in planning the development of a salt marsh on dredged material is the substrate selective properties of the prospective species to be planted.  A number of questions arise:

1.  What are the characteristics of the dredged material?

2.  How do these characteristics change when the dredged material is placed at various elevations in the intertidal zone?

3.  How do the predicted substrate conditions correlate with those found in the soils supporting natural stands of species being considered for planting on the site?

4.  Based on root system dynamics in natural marshes, what would be a minimum estimate of root system productivity in natural dredged material marshes?

5.  Which marsh plants will form dense root mats?

6.  What rooting depth is characteristic of the various plants?

The approach to answering the questions about the substrate selective properties of the plants was to:

1.  Characterize the natural underground productivity and organic matter deposition system by examining the dynamics of the underground macro-organic matter in natural stands of marsh plants in Georgia, Delaware, and Maine.  Methods were developed

which would enable others to conduct similar evaluations on marsh species not included in this study. The results of these studies are detailed in Part II of this report.

2. Characterize the natural soil systems under which the marsh plants in Georgia, Delaware, and Maine grow. Methods were selected which could be followed by District Engineers in these local situations. This study was intended as a beginning of a data set, which would allow correlation of marsh soil and dredged material parameters with observed plant establishment success and productivity measurement. These initial studies are summarized in Part III of this report.

3. Since high marsh S. alterniflora responded to added nitrogen in Delaware, North Carolina, and Georgia, it was hypothesized that the productivity of these and other marsh plants may be enhanced at various sites along the coast. These results give an indication of the nutritional state of the natural plants on soils with certain nutrient characteristics. This information will be valuable in predicting the probable response of the plants to fertilizer added to plants being established on dredged material. Part IV of this report contains the results of a study of plant stands along the western coast of the Atlantic Ocean.

4. There are many types of dredged material, many species of plants, and even more sets of environmental conditions under which they may be placed. Since it was not practical to test

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all combinations, it was felt that bioassay procedures should be developed for growing plants on a variety of dredged material under various conditions. Both a field and a laboratory bioassay test were developed and tested which are described in Parts V and VI of this report. In addition to the methodology, these sections report on several practical problems that were examined using dredged material from five sites.

## PART II: UNDERGROUND BIOMASS PROFILES AND DYNAMICS IN ATLANTIC COASTAL MARSHES

### Introduction

Many studies of aerial plant parts have been reported in the literature, but the dynamics of the underground portions of salt marsh plants have received little attention. Most of the fixed carbon reserves of salt marshes are, however, in the soils (Gallagher, 1974; Valiela et al., 1976). Almost all of the macro-organic matter (retained on a 1-mm sieve) in Georgia salt marshes is identifiable as root, rhizome, or stem base material.

The dynamics of the macro-organic matter (MOM) pool is the net result of numerous processes. Those which add to the pool are root, rhizome, and stem base growth, as well as storage of photosynthate. Translocation to aerial structures, physical disintegration, and microbial decay remove material from the pool. The study was designed to examine the dynamics of the MOM carbon pool in salt marshes along the eastern coast of the United States. This knowledge is important to understanding soil development and stability, microbial dynamics, and ecosystem energetics in the various marsh types along the latitudinal gradient. Knowledge of the underground biomass in these natural marshes can act as a guide to evaluating the maturity of a developing marsh on natural substrate or dredged material.

## Methods

A sampling program, described in Table 1, was conducted from March 1972 to April 1975. Study sites were chosen in Georgia, Delaware, and Maine since they represented the extremes and a central location where marshes are abundant along the United States Atlantic coast. The accessibility of the marsh and availability of laboratory facilities were of secondary consideration in choosing site locations. In Georgia, areas near the University of Georgia Marine Institute were selected. Spartina cynosuroides was sampled on a small island near the mouth of the Altamaha River where water salinity was usually less than 3‰. Borrichia frutescens, Distichlis spicata, Iva frutescens, Spartina patens, and Sporobolus virginicus were sampled in marshes developed along creeks behind the dune complex on the eastern side of Sapelo Island. Spartina alterniflora, Juncus roemerianus, and Salicornia virginica were studied in the Duplin River Estuary on the western side of Sapelo Island. All of the plants in Delaware were sampled in Canary Creek Marsh near Roosevelt Inlet in Lewes, Delaware. The Maine study sites were in Franklin County. Juncus gerardi and creekbank S. alterniflora were collected along Northeast Creek west of Salisbury Cove, and S. patens and creekhead S. alterniflora were sampled in marshes on the south side of Hoy Bay near its head.

Samples were collected and processed for macro-organic matter content by the methods described by Gallagher (1974). An aluminum coring device was used to collect underground organic matter samples, which were washed free of the mineral and micro-organic matter over a 1-mm

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Table 1

Underground Biomass Sampling Program in Atlantic

Coastal Marshes of the United States

| Plant | Location and Sampling Period | Number of Cores | Sampling Intervals (wks.) |
|---|---|---|---|
| Borrichia frutescens | GA(8/73-9/74) | 5 | 8 |
| Distichlis spicata | GA(8/73-9/74) | 5 | 8 |
| | DL(8/73-9/74) | 5 | 8 |
| Juncus gerardi | DL(8/73-9/74) | 5 | 8 |
| | ME(6,8,9/74;4/75) | 5 | 8 |
| Juncus roemerianus | GA(3/72-3/73) | 6 | 4 |
| Phragmites communis* | DL(10/73-9/74) | 3+3** | 8 |
| Salicornia virginica | GA(8/73-9/74) | 5 | 8 |
| | DL(10/73-12/74) | 5 | 8 |
| Spartina cynosuroides | GA(10/73-1/75) | 3+3** | 8 |
| Spartina alterniflora | | | |
| Creekbank | GA(3/72-2/73) | 6 | 4 |
| | ME(6,8,9/74;4/75) | 5 | 8 |
| Creekhead | ME(6,8,9/74;4/75) | 5 | 8 |
| High marsh | GA(3/72-2/73) | 6 | 4 |
| Spartina patens | GA(8/73-9/74) | 5 | 8 |
| | DL(9/74-8/75) | 5 | 8 |
| | ME(6,8,9/74;4/75) | | |
| Sporobolus virginicus | GA(10/73-11/74) | 5 | 8 |

* Phragmites communis is a commonly accepted name for the common reed
and appears throughout many current literary works, however, the
U. S. National Herbarium has recently accepted P. australis as the
proper name for this grass (Personal Communication, 2 August 1977,
Dr. Thomas R. Soderstrom, Agrestologist, Dept. of Botany, Smithsonian
Institute, Washington, D. C.).
** 3 cores taken over stems and 3 between stems.

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sieve with water. Samples dried at 60°C were ground to pass a 40-mesh sieve and analyzed for carbon content with a Leco WR12 Carbon Determinator. Nitrogen was determined by the Kjeldahl method and P, K, Mg, Ca, Mn, and Fe were assayed by spark emission spectrometry (Jones and Warner, 1969).

## Results and Discussion

### Macro-organic Matter Profiles

Macro-organic matter profiles in the marshes were of three shapes (Figure 1). In the first type, the concentration was relatively uniform with depth. Macro-organic matter concentration was highest at the surface and decreased with depth in the second type. The third type had a relatively low concentration near the surface, the highest concentration somewhat below the surface, and low concentrations at greater depth. The marsh types exhibiting the three profile types are listed in Table 2.

Biological, physical, and chemical factors influence the shape and MOM concentrations in the profiles. Plant stem growth has both an input and an output role. When stems are initiated from rhizomes, they can increase the underground biomass, assuming some of the input is coming from current photosynthesis and not exclusively from long-term stored material in rhizomes. Work by Hull et al. (1972) indicates the former is likely. Once the young stems break the soil, any translocation to aerial tissue represents an output. Root and rhizome production have only an input role. Type 1 profiles were present

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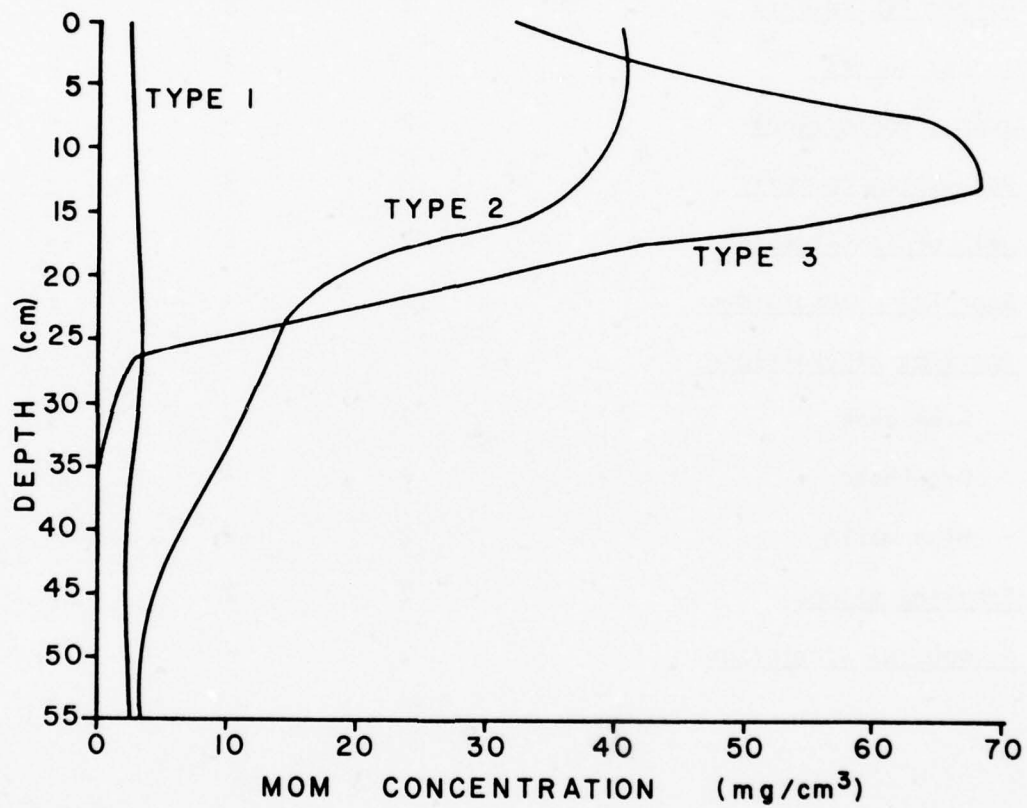
Figure 1

Three Types of Macro-organic Matter Profiles

Table 2

**Macro-organic Matter Profile Types Exhibited by Various Marsh Plants**

**at Three Areas of Eastern Coastal Marshes of the United States**

| Plant | Location* | | |
| --- | --- | --- | --- |
| | Georgia | Delaware | Maine |
| Borrichia frutescens | 2 | - | - |
| Distichlis spicata | 2 | 3 | - |
| Juncus gerardi | - | 2 | 2 |
| Juncus roemerianus | 2 | - | - |
| Phragmites communis | - | 3 | - |
| Salicornia virginica | 2 | 2 | - |
| Spartina cynosuroides | 2 | - | - |
| Spartina alterniflora | | | |
|   Creekbank | 1 | - | 3 |
|   Creekhead | - | - | 1 |
|   High marsh | 2 | - | - |
| Spartina patens | 2 | 2 | 2 |
| Sporobolus virginicus | 2 | - | - |

* Numbers correspond to type of profile shown in Figure I.

where root-shoot ratios were low. In Type 2 profiles, most of the living roots and rhizomes were concentrated within the top 10 cm, whereas in Type 3 profiles, a thick rhizome mat is located 10-20 cm below the surface.

Except in unusual circumstances, the shape of the profiles is dependent primarily on plant species. In Georgia a natural S. alterniflora marsh forming on a protected sand beach developed the typical Type 2 profile in 2 years. Although the concentration of MOM was somewhat lower than in older adjacent marshes, the shape of the profile was the same. Similar results were obtained with S. virginicus which developed its typical Type 2 profile within 18 months after being planted on 3 types of dredged material in Georgia.

The major departure from a single profile type for a single species was seen with S. alterniflora, which grew in a wider range of sites both latitudinally and at various habitats at a single latitude. In Georgia the creekbank S. alterniflora has a Type 1 profile while that growing further north has a Type 2. Current evidence is that these differences are environmental rather than genetic. The deeper rooting pattern may be due to better water movement in the creekbank soils (Odum and Riedeburg, 1976). The higher salinity of the soils in the high marsh (35-40‰ compared to 20-28‰ on the creek bank) may restrict the roots to the upper zone where rainfall and tidal water keep the salinities lowest. Haines and Dunn (1976) have reported a reduction in root growth associated with higher salinity media.

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When apparent anomalies occur, the historical aspect of the development of the marsh may be important in determining the type of profile found. Fox example, the typical S. virginica stands in Delaware had Type 2 profiles, but one stand was cored which had a Type 1. By examining the MOM and the soil, it was found that the site had been a S. alterniflora marsh on which a thin layer of dredged material had been deposited. This latter substrate was the site for the S. virginica development. The S. virginica root system provided the total input of MOM in the upper 15 cm and the smothered S. alterniflora that for the next 20 cm; these two superimposed Type 2 profiles produced a Type 1 profile.

Although the concentration of macro-organic matter changed during the year, the shape of the profiles did not change significantly in most cases (Figure 2). The major shift was from a Type 2 profile toward a Type 1 as the macro-organic matter in the upper portion of the profile decayed. Since all stands were sampled at 8-week intervals, it was possible to plot an annual cycle for each species. In some stands of marsh plants, clear smooth annual cycles in macro-organic matter were measured (Figure 3) while in others the cycle was less clear (Figure 4). In most stands the culm density was high enough that the cores were large enough to produce means with satisfactory variability. In the stands of S. cynosuroides and Phragmites communis, random samples gave very variable results and collection procedures were modified to remove a pair of cores at randomly selected points. One core was removed from directly over a cut stem base
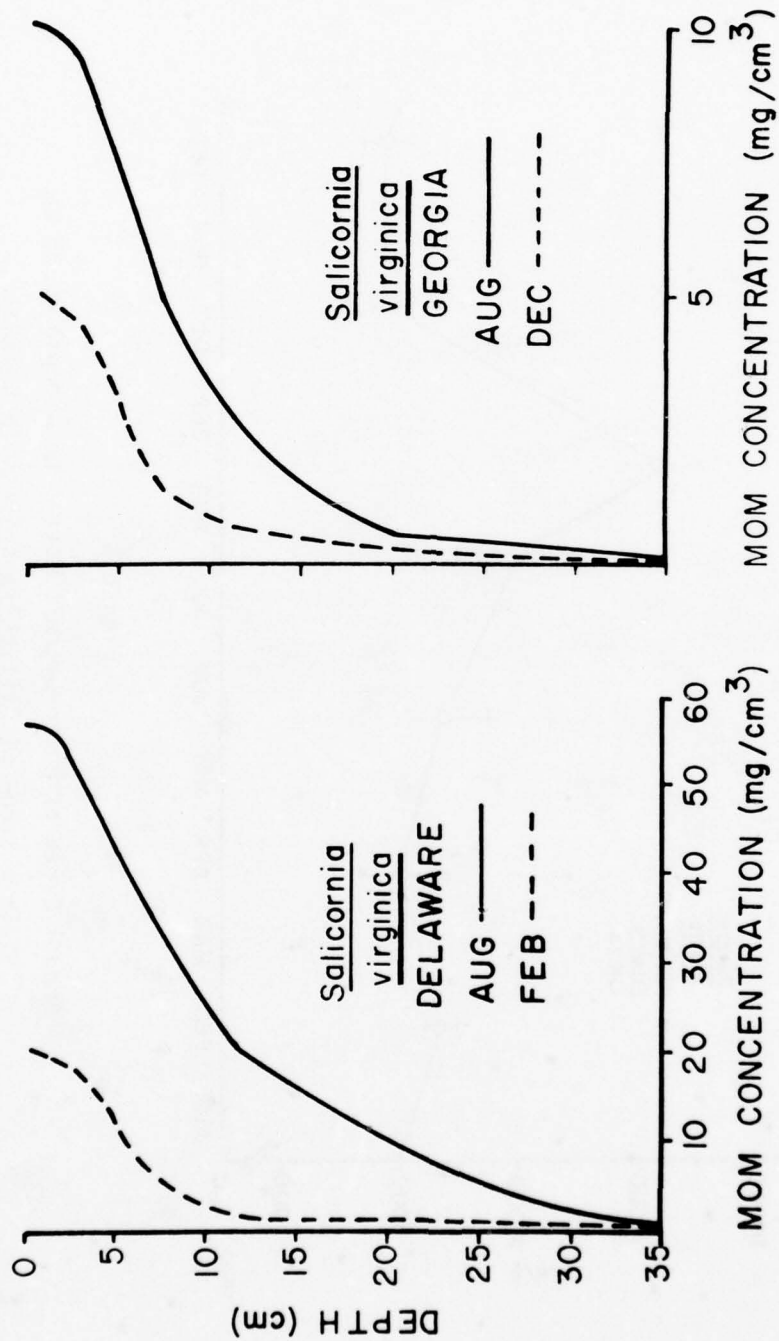
Figure 2

Macro-organic Matter Profiles in _Salicornia virginica_

in Delaware and Georgia
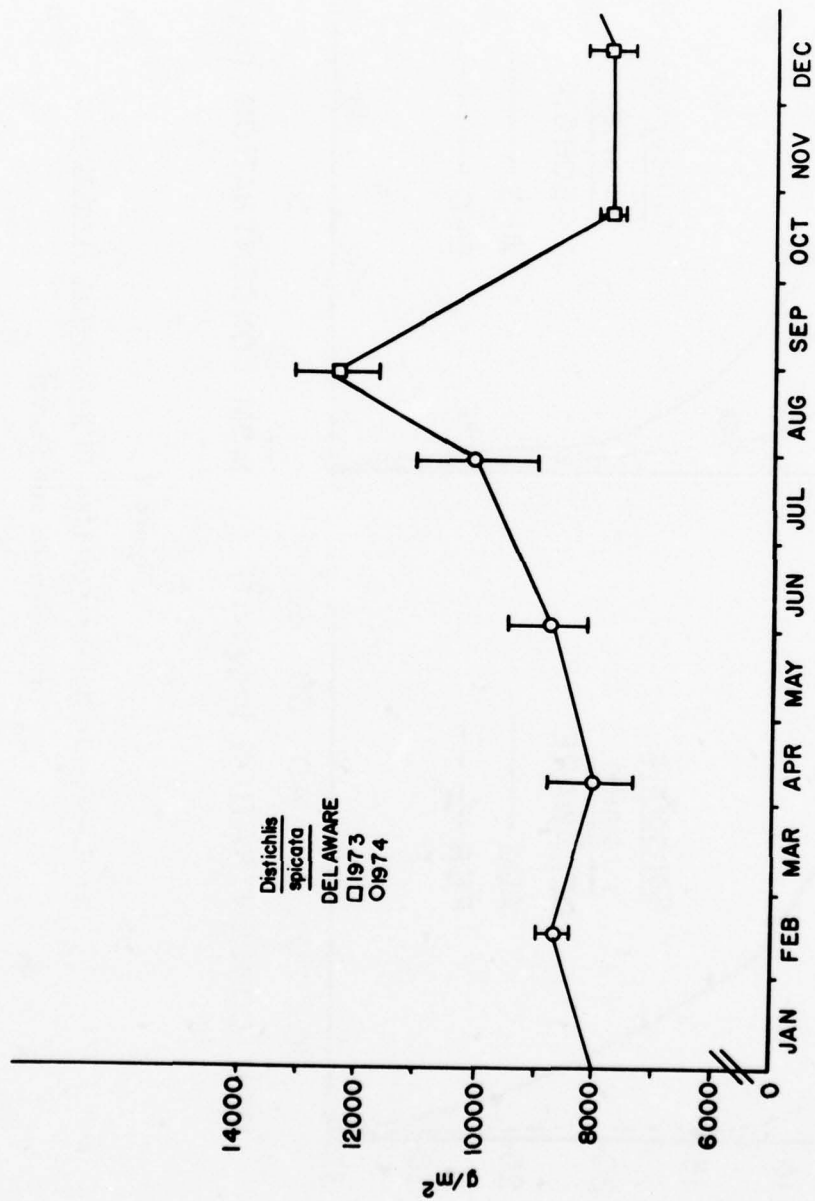
Figure 3

Annual Cycle of Macro-organic Matter to a Depth of 35 cm
in a Stand of Distichlis spicata in Delaware.

Bars Represent ± 1 SE
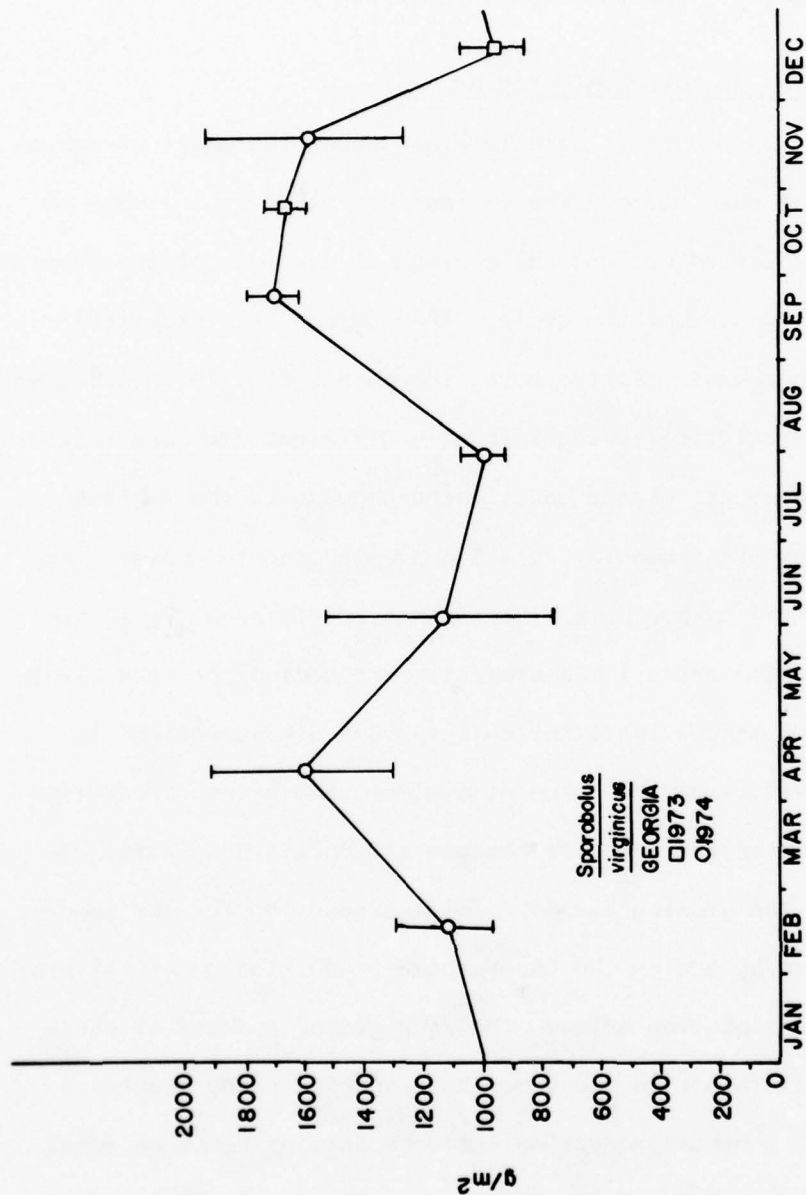
Figure 4

Annual Cycle of Macro-organic Matter to a Depth of 35 cm

in a Stand of _Sporobolus virginicus_ in Georgia.

Bars Represent ± 1 SE

while the other member of the pair was taken from between the stem bases. The annual cycle of these two areas within the stand of S. cynosuroides is illustrated in Figure 5. Data for each sampling date for the various plant stands are found in Appendix A.

## Annual Increment of Macro-organic Matter

These cycles were used to calculate an annual increment of macro-organic matter for each stand. The maximum was taken as the mean of the several highest readings and the minimum as the mean of the several points from the low part of the cycle. This method had the effect of minimizing the increment. Furthermore, the points used in calculating a mean were not statistically significantly different from one another.

The carbon contents of the underground biomass in the various marsh plant stands are shown in Table 3 and were used to convert the dry weight data to a carbon base. No seasonal differences in carbon content were detected and all measurements were pooled for each stand. The results of the annual increment calculations are summarized in Table 4. These values may be taken as minimum underground production figures. They err on the low side because the underground parts die and decay during the growing season. Total production for the species cannot be obtained by adding the underground production to aerial production since translocation between the underground and aerial parts of the plants will result in the same photosynthate being counted twice. The total minimum production estimate must be based on total maximum and minimum biomass data obtained from a simultaneous aerial and underground sampling program.

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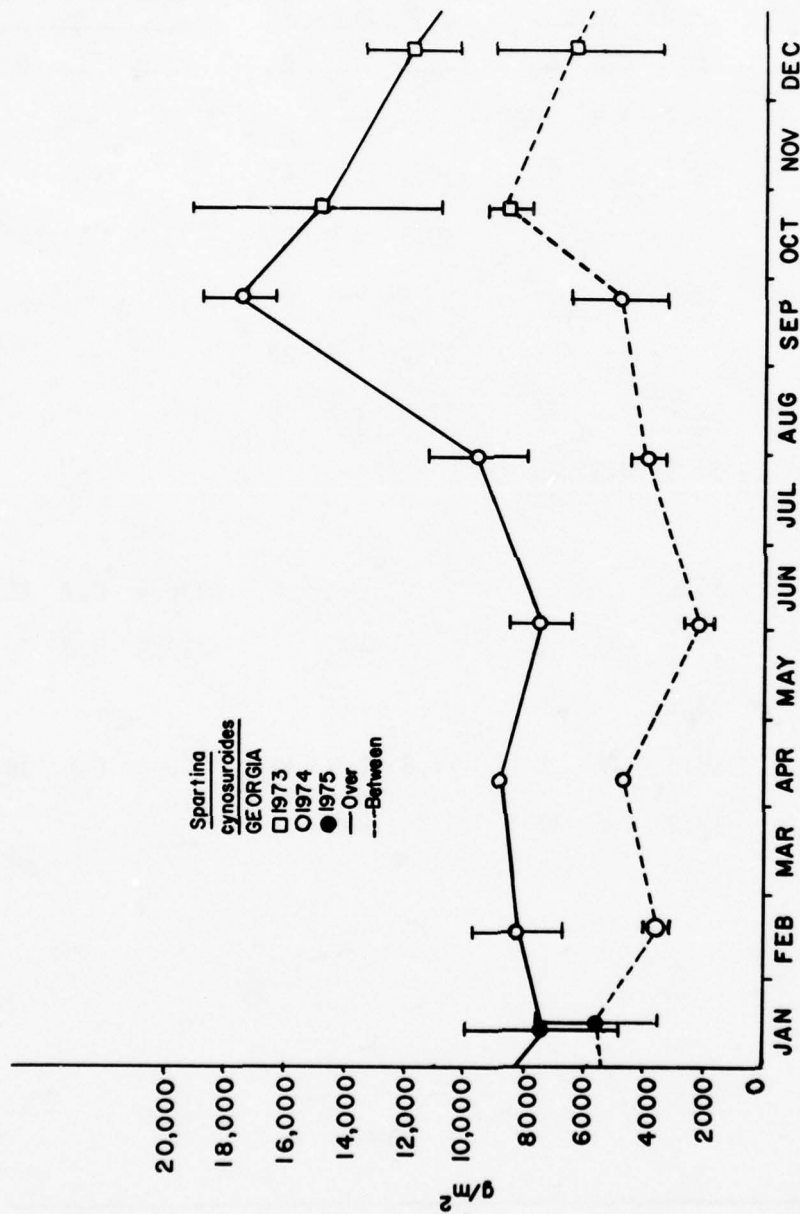
Figure 5

Annual Cycle of Macro-organic Matter to a Depth of 55 cm

in a Stand of Spartina cynosuroides in Georgia.

Solid Line Represents Cores Taken Over Stems;

Broken Line Represents Cores Removed from

Between Stems. Bars Represent ± 1 SE

<div align="center">

Table 3

Carbon Content ($g\ C/m^2$) of the Underground Biomass

in Stands of Salt Marsh Plants

</div>

| Species | Georgia | | | Delaware | | | Maine | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\overline{X}$ | SE | N | $\overline{X}$ | SE | N | $\overline{X}$ | SE | N |
| Borrichia frutescens | 39.2 | 1.4 | 7 | | -- | | | -- | |
| Distichlis spicata | 39.3 | 2.5 | 14 | 39.7 | 0.8 | 43 | | -- | |
| Juncus gerardi | | -- | | 39.4 | 0.9 | 29 | 33.4 | 1.1 | 20 |
| Juncus roemerianus | 39.9 | | | | -- | | | -- | |
| Phragmites communis | | -- | | 37.0 | 1.2 | 27 | | -- | |
| Salicornia virginica | 32.4 | 1.0 | 11 | 37.0 | 1.8 | 16 | | -- | |
| Spartina cynosuroides | 36.5 | 0.9 | 25 | | -- | | | -- | |
| Spartina alterniflora | | | | | | | | | |
|   Creekbank | 36.5 | | | | -- | | 36.6 | 0.7 | 20 |
|   Creekhead | | -- | | | -- | | 39.5 | 3.8 | 9 |
|   High marsh | 38.1 | | | | -- | | | -- | |
| Spartina patens | 38.8 | 1.2 | 8 | 31.8 | 2.6 | 12 | 40.6 | 0.4 | 20 |
| Sporobolus virginicus | 38.0 | 2.6 | 11 | | -- | | | -- | |

$\overline{X}$ = arithmetic mean, SE = standard error of the mean, N = number of samples.

Table 4

Annual Increment and Turnover Times of the Underground

Macro-organic Matter in Stands of Salt Marsh Plants

| Plant | Annual Increment (g C/m$^2$) | | | Turnover Time (months) | | |
|---|---|---|---|---|---|---|
| | G | D | M | G | D | M |
| Spartina alterniflora | | | | | | |
| Creekbank | 771 | - | 476 | 18.5 | - | 118.8 |
| Creekhead | - | - | 80 | - | - | 224.4 |
| High marsh | 768 | - | - | 57.1 | - | - |
| Spartina patens | 117 | 149 | 220 | 67.8 | 91.6 | 91.6 |
| Spartina cynosuroides | 1304 | - | - | 28.0 | - | - |
| Sporobolus virginicus | 221 | - | - | 33.9 | - | - |
| Distichlis spicata | 424 | 1348 | - | 40.6 | 39.5 | - |
| Phragmites communis | - | 1338 | - | - | 27.4 | - |
| Juncus gerardi | - | 1686 | 543 | - | 22.1 | 45.6 |
| Juncus roemerianus | 1338 | - | - | 44.0 | - | - |
| Salicornia virginica | 142 | 528 | - | 26.4 | 24.5 | - |
| Borrichia frutescens | 321 | - | - | 18.4 | - | - |

G = Georgia,  D = Delaware,  M = Maine.

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The time to turn over the total macro-organic matter pool in the soil was calculated by dividing the increment into the maximum biomass. This total pool is no doubt composed of several sub-pools with different turnover times, with the most rapid turnover in a matter of days and the most refractory taking centuries.

In Georgia stands of S. alterniflora, the creekbank and high marsh had equal annual increments but the turnover time was much more rapid in the creekbank area due to the threefold greater quantity of MOM in the high marsh. In comparing the Georgia creekbank with a similar site in Maine, the increment was found to be about 60% of the Georgia stand while the turnover time was 6 times longer in the cooler area. On the other hand, the annual increment of S. patens increased with latitude. This might be expected since S. patens is a much more important component of the marsh flora at the higher latitudes. Similarly, D. spicata, whose annual increment increased with latitude, is more prevalent in the Delaware marsh than in Georgia.

These data indicate that the dynamics of the underground macro-organic matter is as great or often greater than the aerial dynamics. The factors regulating the translocation of photosynthate to the underground pool and the dispersion of this stored carbon either back to the aerial parts of the plant or to the soil detritus food web are of immense consequence to the salt marsh ecosystem and are now the subject of this research.

## Mineral Composition

The mineral composition of the underground macro-organic matter was typified by the D. spicata data shown in Table 5. Data on the mineral composition of other species are found in Appendix B. Nitrogen, phosphorus, and potassium all decreased with depth. The deeper samples appeared to contain more dead material and hence would be expected to have lower quantities of the macronutrients. Nitrogen, for example, will likely be conserved and removed from the dying tissue. Since the potassium is not bound to compounds in the plants but exists as a free ion, it will leach quickly when the integrity of the membranes is lost as the cells senesce. No particular pattern was seen for Ca, Mg, Mn, or C; but a pattern similar to that for N, P, and K was observed for Zn.

When the quantity of N bound in the MOM was compared along the latitudinal gradient using June harvest data, the highest quantity was found at the most northerly sites in 4 of the 5 cases studied (Table 6). In all cases the C:N ratio decreased with increasing latitude. The mean areal nitrogen content for the underground MOM for all the species studied was 65.4 g $N/m^2$ with a coefficient of variation of 70. The mean C:N ratio for the same species was 35.5 with a coefficient of variation of only 19. Thus the relative amount of N to the C present is more consistent from one plant stand to another than is the absolute amount of N.

Table 5

Mineral Composition of Underground Macro-organic Matter in a Stand of

Distichlis spicata in Delaware in February, June, and November

| Month | Depth cm | Percent | | | | | PPM | | |
|-------|----------|---------|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | Mn | Cu | Zn |
| February | 0-5 | 1.39(.04)* | .13(.02) | .35(.09) | .31(.14) | .26(.04) | 20(10) | 17(7) | 179(33) |
| | 5-10 | 1.18(.09) | .08(.03) | .34(.09) | .26(.03) | .32(.02) | 20(4) | 20(9) | 140(122) |
| | 10-15 | 1.00(.16) | .03(.03) | .19(.10) | .21(.03) | .28(.07) | 9(4) | 16(9) | 36(16) |
| | 15-35 | .98(.04) | .01(.01) | .08(.14) | .22(.08) | .22(.05) | 20(4) | 5(4) | 45(32) |
| June | 0-5 | 1.33(.11) | .15(.07) | .33(.05) | .20(.04) | .25(.06) | 31(7) | 13(4) | 159(66) |
| | 5-10 | 1.35(.11) | .10(.04) | .25(.05) | .24(.04) | .32(.03) | 32(3) | 22(4) | 64(14) |
| | 10-15 | 1.39(.10) | .08(.03) | .20(.03) | .34(.05) | .33(.03) | 29(2) | 20(2) | 40(14) |
| | 15-35 | .91(.14) | .02(.02) | .08(.03) | .24(.10) | .19(.08) | 14(8) | 6(2) | 39(14) |
| November | 0-5 | 1.45(.07) | .12(.06) | .34(.17) | .43(.13) | .34(.08) | 25(9) | 17(9) | 84(15) |
| | 5-10 | 1.27(.04) | .06(.03) | .25(.13) | .35(.03) | .39(.03) | 16(5) | 21(11) | 26(12) |
| | 10-15 | 1.00(.24) | .07(.02) | .27(.10) | .36(.04) | .26(.04) | 18(2) | 18(6) | 22(6) |
| | 15-35 | .75(.06) | .08(.04) | .15(.14) | .31(.10) | .23(.06) | 27(16) | 11(7) | 24(13) |

* Numbers in parentheses are standard errors.

Table 6

Grams N/m$^2$ to a Depth of 35 cm and C:N Ratios of

Underground Macro-organic Matter from Stands of Marsh Plants

| Plant | Location | g N/m$^2$ | C:N |
|---|---|---|---|
| Borrichia frutescens | GA | 12 | 39 |
| Distichlis spicata | GA | 44 | 33 |
| | DL | 156 | 28 |
| Juncus gerardi | DL | 94 | 33 |
| | ME | 68 | 30 |
| Juncus roemerianus | GA | 123 | 40 |
| Phragmites communis | DL | 83 | 37 |
| Salicornia virginica | GA | 12 | 27 |
| | DL | 41 | 26 |
| Spartina cynosuroides | GA | 70 | 41 |
| Spartina alterniflora | GA* | 98 | 38 |
| | ME† | 129 | 32 |
| Spartina patens | GA | 14 | 48 |
| | DL | 27 | 45 |
| | ME | 61 | 29 |
| Sporobolus virginicus | GA | 15 | 42 |

* High marsh.
† Creekbank.

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PART III: COMPARISON OF SOME TIDAL MARSH SOILS
ALONG THE ATLANTIC COAST

## Introduction

Interest in salt marsh soils has increased since the value of marshes
as natural resources and as their potential for development has been
realized. Concern has developed about how to restore damaged marshes or
create new marsh areas to replace those destroyed by development and
pollution. The U. S. Army Corps of Engineers has taken the initiative in
creating marshes on dredged material. A knowledge of the properties of
marsh soils is necessary for two reasons. First, the description of marsh
soils is useful in order to predict the soil requirements for various
plants. Second, the information enables the scientist to tell how far a
newly established marsh has progressed toward the conditions of a natural
marsh.

The soil descriptions included in this report cover a wide range of
situations from Maine to Georgia. They were selected because they were
believed to bracket all of the types which might be encountered along the
east coast of the United States.

## Methods

The approach in this study was to make field descriptions on the
sites by either working from the faces of large walk-in pits or with
shovel samples removed from small ($0.5 \text{ m}^2$) pits. The former technique
was used in the better drained and firmer substrates while the latter

was used in areas where the water table was near the surface or the sub-strate was not firm enough to support the wall.

Bulk density was obtained using a series of short cores so that compaction would not be a problem (Gallagher, 1974). In situ pH was obtained by placing the probe directly in the moist soil.

Soil samples were removed from each of the horizons and returned to the laboratory where they were freeze-dried and ground in a Wiley mill until they passed a 40-mesh sieve. In addition to the soils collected at the study sites, three types of dredged material were collected and analyzed in the same way as the soils. All materials were collected from near the low tide elevation and are thus more characteristic of the fresh dredged material than that piled high in the intertidal zone. All samples were taken from dredged material placed at the site less than 90 days earlier. The silt and clay material was collected from a site 300 meters north of the drawbridge leading to Jekyll Island on the western side of the Inland Waterway. The sand substrate was collected from the eastern side of Buttermilk Sound on the site which was subsequently to be a marsh-creation site developed by the Dredged Material Research Program (DMRP). The third was a sand and clay mixture collected from the north side of the Darien River where it intersects with May Hall Creek.

Salinity characteristics were measured by putting 100 grams of soil on No. 54 Whatman filter paper in a funnel and leaching it with successive 50-ml volumes of distilled water. Each leachate salinity was measured and the leachate saved. When the salinity of the last leachate increment was zero, the total amount of water was called the leaching volume. The soil

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salinity was calculated from the salinity of the leachate and the volume
of the water collected. The leaching volume was divided by soil salinity
to give an index (desalination index) of the ease of removing the salt
from the soil.

The pH of the dried and oxidized soil was measured first in a 1:1
water:soil mixture ($pH^W$) and then after treatment with buffer solution
($pH^B$) as described by Adams and Evans (1962). Total N content was deter-
mined by Kjeldahl digestion (Bremner, 1965). A double acid extraction of
a soil sample was performed using HCl and $H_2SO_4$ according to the methods
described by Nelson et al. (1953). The extract was analyzed for P, K, Ca,
and Mg according to the methods described by Isaac and Jones (1970).
Sodium, iron, and manganese were assayed by atomic absorption spectroscopy
(Isaac and Kerber, 1971). Ammonium and nitrate nitrogen were measured
by the methods described by Bremner and Keeney (1966) and chloride by
potentiometric titration (Lacroix et al., 1970).

## Results and Discussion

### Soil Profiles and Structure

The profile descriptions for soils from Georgia, Delaware, and Maine
are shown in Appendix C. Colors were primarily blacks, grays, and greens
reflecting the waterlogged reduced nature of these soils. In Georgia and
Delaware the soils higher in the intertidal zone tended toward lighter
texture. Since these soils are inundated less frequently by silt and clay-
laden tidal water, deposition of finer grade sediments was less. The
coarse-grained sediments were loose with little evidence of ped formation.

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Similarly, the fine-grained sediments were massive and little structural development occurred presumably because of the effects of the high sodium content of the soil. In the J. gerardi stand in Delaware, subangular blocky peds were found.

Bulk density profiles for soils from the three states are shown in Figures 6, 7, 8. The Georgia profiles were generally more uniform with depth than were those from the other two states. Two groups could be distinguished from the Georgia set. Salicornia virginica, S. patens, and S. virginicus which developed on sandy substrate formed one group, while B. frutescens, D. spicata, and S. cynosuroides which developed on substrates composed primarily of silt and clay formed a second.

The much lower bulk densities generally measured at the surface in Delaware and Maine reflect the greater peat development at these locations. Slower decay rates and lower silt loads in the water are probably the major factors responsible for these differences.

The in situ reaction of the soils varied from 8.8 in soil horizon A11 in D. spicata in Georgia to 5.0 in soil horizon A22g in J. gerardi in Maine (Appendix C).

The higher values are typical of those found in seawater. Most of the values were close to pH 7.0 and much of the variation around that point may reflect the effects of the wetness of the soil on the $Na^+$, $H_3O^+$ balance in the soil (Table 7). As the moisture increases the $H_3O^+$ becomes more abundant relative to the $Na^+$ and more $H_3O^+$ is associated with the cation exchange capacity (C.E.C.) sites in the soil. This condition leaves relatively more $OH^-$ in solution and the pH rises. In the cases where the pH was found to be low, organic acids resulting from anaerobic
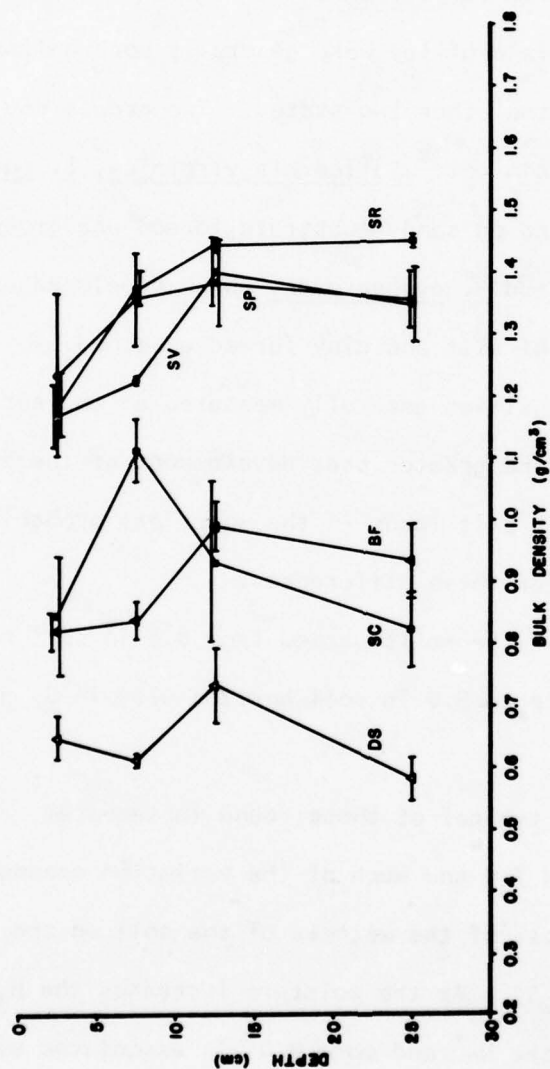
Figure 6

Bulk Density (g/cm$^3$) Profiles from Marsh Soils in Georgia.
BF-Borrichia frutescens, DS-Distichlis spicata,
SC-Spartina cynosuroides, SP-Spartina patens,
SR-Sporobolus virginicus, SV-Salicornia virginica

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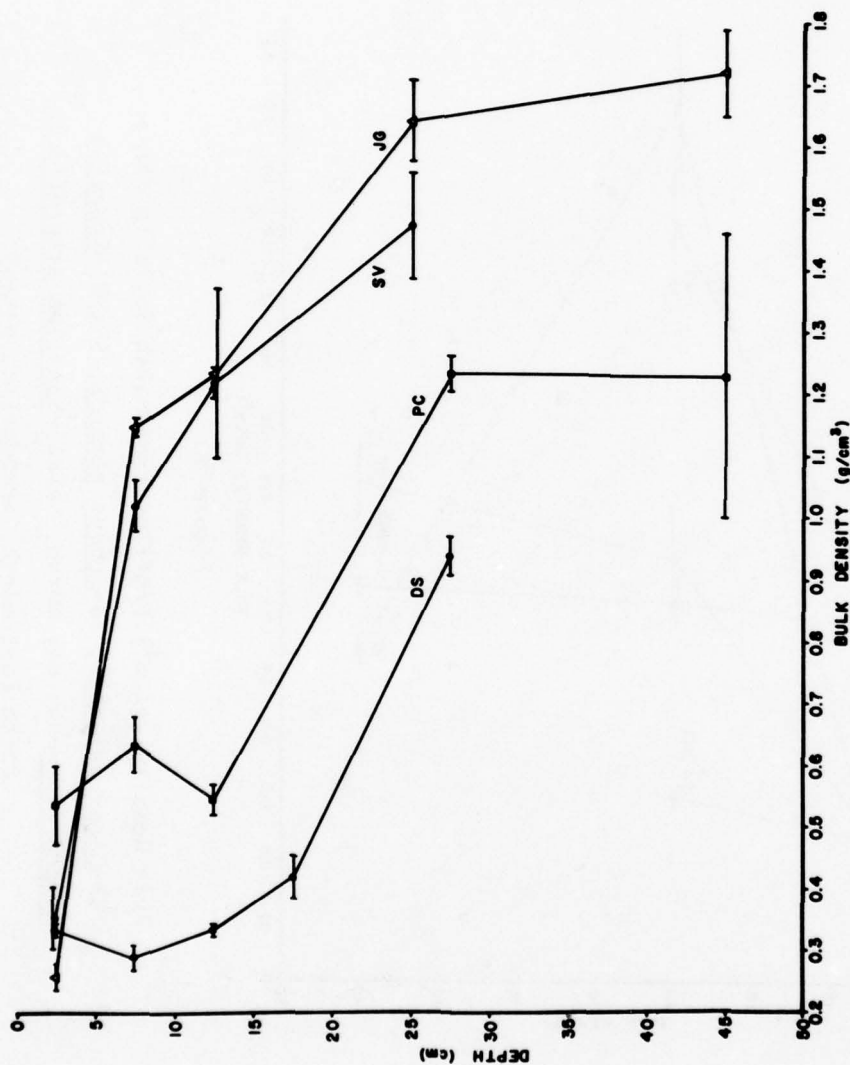
Figure 7

Bulk Density (g/cm³) Profiles from Marsh Soils in Delaware.
DS-Distichlis spicata, JG-Juncus gerardi,
PC-Phragmites communis, SV-Salicornia virginica

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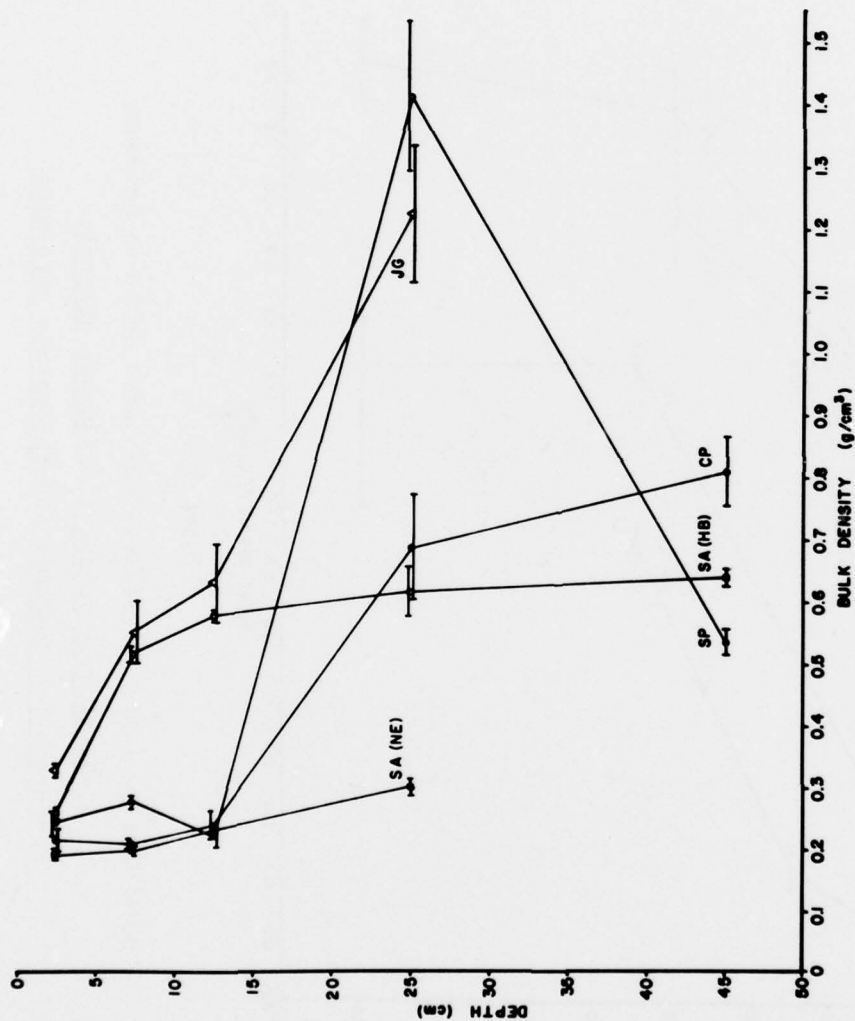
Bulk Density (g/cm$^3$) Profiles from Marsh Soils in Maine.

CP-<u>Carex paleacea</u>, JG-<u>Juncus gerardi</u>, SA(HB)-<u>Spartina</u>
<u>alterniflora</u>-Hoy Bay marsh, SA(NE)-<u>Spartina alterniflora</u>-
North East marsh, SP-<u>Spartina patens</u>

Figure 8

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Table 7

Effect of Soil-Water Ratio on the pH of

Spartina alterniflora Marsh Soils

| Parts Soils | Parts Water | pH |
|:---:|:---:|:---:|
| 2 | 0 | 6.90 |
| 2 | 1 | 7.05 |
| 2 | 2 | 7.18 |
| 1 | 2 | 7.34 |
| 0 | 2 | 6.00 |

decay may be responsible for the acidic condition. In none of the cases where the pH was low did the soils appear well enough aerated to have oxidized sulfides and thus exhibit the cat-clay phenomenon.

## Salinity

The salinity characteristic of the soil (Table 8) is one of the important properties determining which plants can thrive, or, in fact, survive. The first characteristic which was measured was the salt concentration. These data indicate the salinity characteristic of the soil on which the various marsh plants grow. These numbers do not, however, reflect the salinity to which the plants are exposed since the moisture content of the soil will cause the interstitial water salinity to vary widely. Gallagher and Daiber (1974) reported interstitial water salinities in a salt pan ranged from 34‰ in the spring to 89‰ in the summer Although the salinity on a dry weight basis does not indicate the condition under which the plants might be growing at any given time, it is a relatively conservative property which, when coupled with the moisture content, will indicate the stress under which the plant will be placed. The three types of dredged material from Georgia were widely different in salinity, and hence the kinds of plants they might support would depend on the moisture regime under which they might be placed and the degree to which they were leached by rainfall or low salinity tidal water. In order to determine how readily the salt could be removed, the soil was leached with increments of fresh water until no more salts could be removed. This leaching volume was divided by the salinity to give a desalination index. The higher the

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## Table 8

### Salinity Characteristics of Soil Horizons
### from Several Stands of Marsh Plants

| Species | Depth (cm) | Concen- tration (‰) | Salt Leaching Volume (ml) (LV) | Desali- nation Index (DI) |
|---|---|---|---|---|
| GEORGIA | | | | |
| Borrichia frutescens | 0-4 | 17 | 720 | 42 |
| | 4-28 | 8 | 720 | 90 |
| | 28-64 | 11 | 480 | 44 |
| | 64-125 | 12 | 240 | 20 |
| Distichlis spicata | 0-37 | 32 | 1200 | 38 |
| | 37-100 | 18 | 880 | 49 |
| | 100-135+ | 13 | 560 | 43 |
| Salicornia virginica | 0-7 | 16 | 320 | 20 |
| | 7-32 | 21 | 240 | 11 |
| | 32-80 | 19 | 240 | 13 |
| | 80-125 | 19 | 880 | 46 |
| Spartina cynosuroides | 5-20 | 6 | 240 | 40 |
| | 20-52 | 4 | 160 | 40 |
| | 52-85 | 6 | 480 | 80 |
| Spartina patens | 0-25 | 12 | 160 | 13 |
| | 25-47 | 8 | 240 | 30 |
| | 47-130 | 8 | 240 | 30 |
| | 130+ | 6 | 240 | 40 |
| Sporobolus virginicus | 0-3 | 7 | 160 | 23 |
| | 3-13 | 9 | 240 | 27 |
| | 13-34 | 7 | 160 | 23 |
| | 34-150+ | 6 | 160 | 27 |
| Dredged material | silt & clay | 148 | 2320 | 16 |
| | sand | 1 | 20 | 20 |
| | sand & clay | 9 | 160 | 18 |

(Continued)

LV = volume (ml) of fresh water necessary to remove leachable
    salts from 100 grams of soil

DI = leaching volume (LV)/soil salinity (‰).

Table 8 (Continued)

| Species | Depth (cm) | Concen- tration (‰) | Salt Leaching Volume (ml) (LV) | Desali- nation Index (DI) |
|---|---|---|---|---|
| **DELAWARE** | | | | |
| _Distichlis_ _spicata_ | 19-29 | 11 | 480 | 44 |
| | 29-45 | 9 | 400 | 44 |
| _Juncus_ _gerardi_ | 0-20 | 5 | 400 | 80 |
| | 20-30 | 8 | 320 | 40 |
| | 30-50 | 6 | 240 | 40 |
| | 50-80 | 4 | 160 | 40 |
| _Phragmites_ _communis_ | 0-25 | 0 | 0 | |
| | 25-75 | 2 | 160 | 80 |
| | 75+ | 4 | 240 | 60 |
| _Salicornia_ _virginica_ | 0-8 | 13 | 560 | 43 |
| | 8-53 | 6 | 240 | 40 |
| | 53-70 | 6 | 240 | 40 |
| _Spartina_ _patens_ | 15-35 | 22 | 1120 | 51 |
| | 35-65 | 20 | 960 | 48 |
| | 65-100+ | 5 | 560 | 112 |
| **MAINE** | | | | |
| _Carex_ _paleacea_ | 0-23 | 46 | 2240 | 49 |
| | 23-46 | 21 | 960 | 46 |
| | 46-71 | 14 | 640 | 46 |
| | 71-97 | 9 | 880 | 98 |
| _Juncus_ _gerardi_ | 0-3 | 20 | 960 | 48 |
| | 3-8 | 16 | 720 | 45 |
| | 15-25 | 3 | 240 | 80 |
| | 25-30 | 8 | 320 | 40 |
| | 30-43 | 3 | 240 | 80 |
| | 43-89 | 4 | 320 | 80 |
| | 89-114 | 4 | 320 | 80 |

(Continued)

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Table 8 (Concluded)

| Species | Depth (cm) | Salt | | |
| --- | --- | --- | --- | --- |
| | | Concentration (‰) | Leaching Volume (ml) (LV) | Desalination Index (DI) |
| MAINE, continued | | | | |
| Spartina alterniflora creekbank | 0-13 | 67 | 2080 | 31 |
| | 13-28 | 39 | 1120 | 29 |
| | 28-41 | 11 | 480 | 44 |
| | 41-91 | 0 | 0 | 0 |
| Spartina alterniflora high marsh | 15-25 | 14 | 640 | 46 |
| | 25-61 | 16 | 800 | 50 |
| | 61-94 | 18 | 800 | 44 |
| Spartina patens | 0-8 | 57 | 2720 | 48 |
| | 8-15 | 61 | 1920 | 31 |
| | 15-28 | 40 | 2320 | 48 |
| | 28-61 | 25 | 1040 | 42 |
| | 61-102 | 25 | 1200 | 48 |

index the more difficult the salt was to remove.  In the case of the
three types of dredged material, although the salinity was greatly dif-
ferent and leaching volume (LV) varied by 2 orders of magnitude, the
ease with which each unit of salinity was removed was similar.  In con-
trast, in the B. frutescens the desalination index (DI) for the 4-28 cm
horizon was 4.5 times that for the 64-125 cm zone.

## pH

The pH characteristics (Tables 9, 10, 11) of the freeze-dried
soils are expressed as $pH^W$ for the samples mixed with water and $pH^B$
for those measured in buffer.  When these are combined with pH in situ,
the reaction of the material being exposed to oxidation can be assessed.
The drop in pH from the in situ reading to the $pH^W$ measurement indi-
cates what would be expected if the substrate were placed higher in
the intertidal zone as the result of dredging or if the soils were
drained.  While the $pH^W$ gives an indication of the intensity of the
acidity, $pH^B$ is an indicator of the quantity of hydronium ions present.
In Table 9, for example, the pH of the 64-125 cm horizon in B. frutes-
cens has a $pH^W$ of 4.1 indicating a low pH probably caused by oxidation
of sulfides.  The $pH^B$ is 7.5, only half a unit below the original
buffer pH of 8.0 indicating the acid buffering capacity is not great.
This contrasts with the situation in the 0-37 cm horizon of D. spicata
(Table 9) where the $pH^W$ was 5.0 and the $pH^B$ dropped to 6.4 indicating
a high lime requirement to neutralize the oxidation effects.

## Table 9

### Chemical Properties of Tidal Marsh Soil Along the Atlantic Coast (Georgia)*

| Depth cm | $pH^W$ | $pH^B$ | P | K | Ca | Mg | Na | Fe | Mn | Cl | $NO_3$ | Total N | Total C | $NH_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Borrichia frutescens** | | | | | | | | | | | | | | |
| 0-4 | 7.2 | 7.7 | 48 | 563 | 3240 | 1130 | 1600 | 10 | 33 | 96,400 | 13.0 | 0.27 | 1.97 | 21.0 |
| 4-28 | 6.6 | 7.8 | 114 | 558 | 3300 | 1120 | 1450 | 14 | 20 | 56,700 | 24.0 | 0.22 | 1.22 | 56.0 |
| 28-64 | 6.5 | 7.7 | 230 | 350 | 3000 | 700 | 1350 | 28 | 12 | 51,000 | 27.0 | 0.18 | 0.58 | 27.0 |
| 64-125 | 4.1 | 7.5 | 370 | 220 | 2580 | 490 | 1050 | 52 | 1 | 22,700 | 7.0 | 0.08 | 0.40 | 13.0 |
| **Distichlis spicata** | | | | | | | | | | | | | | |
| 0-37 | 5.0 | 6.4 | 6 | 188 | 1620 | 630 | 1430 | 8 | 3 | 164,500 | 66.0 | 1.06 | 14.31 | 8.0 |
| 37-100 | 5.0 | 6.6 | 9 | 275 | 2820 | 1100 | 1440 | 2 | 1 | 56,700 | 25.0 | 0.43 | 5.59 | 27.0 |
| 100-135 | 5.1 | 7.8 | 20 | 200 | 1860 | 655 | 1100 | 3 | 1 | 48,200 | 7.0 | 0.15 | 2.80 | 33.6 |
| **Salicornia virginica** | | | | | | | | | | | | | | |
| 0-7 | 7.3 | 7.8 | 6 | 300 | 2760 | 970 | 1670 | 44 | 3 | 53,800 | 15.4 | 0.07 | 0.31 | 63.0 |
| 7-32 | 7.3 | 7.9 | 2 | 250 | 2520 | 810 | 1840 | 14 | 4 | 144,600 | 22.0 | 0.07 | 0.14 | 87.0 |
| 32-80 | 7.6 | 7.9 | 4 | 250 | 2580 | 810 | 1590 | 10 | 1 | 31,900 | 6.0 | 0.15 | 0.10 | 61.0 |
| 80-125 | 6.0 | 7.7 | 19 | 608 | 3300 | 1120 | 2370 | 37 | 1 | 195,600 | 3.0 | 0.08 | 0.55 | 1.0 |

(Continued)

* Total N and C are in % while all other ions are in PPM.

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Table 9 (Concluded)

| Depth cm | $pH^W$ | $pH^B$ | P | K | Ca | Mg | Na | Fe | Mn | Cl | $NO_3$ | Total N | Total C | $NH_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spartina cynosuroides | | | | | | | | | | | | | | |
| 5-20 | 6.3 | 7.8 | 120 | 238 | 2520 | 590 | 540 | 28 | 34 | 25,500 | 11.0 | 0.10 | 0.96 | 1.0 |
| 20-52 | 7.0 | 7.8 | 210 | 153 | 2280 | 380 | 360 | 48 | 19 | 14,200 | 8.4 | 0.10 | 0.62 | 25.2 |
| 52-85 | 6.2 | 7.6 | 32 | 265 | 1800 | 430 | 510 | 165 | 11 | 31,200 | 15.4 | 0.21 | 2.29 | 49.0 |
| Spartina patens | | | | | | | | | | | | | | |
| 0-25 | 6.3 | 7.8 | 120 | 213 | 1920 | 525 | 1140 | 27 | 2 | 14,200 | 4.0 | 0.11 | 0.65 | 1.0 |
| 25-47 | 5.9 | 7.8 | 20 | 150 | 1500 | 470 | 1060 | 6 | 1 | 36,900 | 13.0 | 0.12 | 0.30 | 64.0 |
| 47-130 | 5.9 | 7.4 | 126 | 205 | 1740 | 630 | 850 | 2 | 1 | 11,300 | 19.6 | 0.12 | 1.30 | 94.0 |
| 130-160 | 5.7 | 7.6 | 160 | 263 | 1320 | 490 | 870 | 9 | 1 | 48,200 | 24.0 | 0.09 | 0.30 | 14.0 |
| Sporobolus virginicus | | | | | | | | | | | | | | |
| 0-3 | 6.9 | 8.0 | 6 | 163 | 1440 | 460 | 860 | 9 | 1 | 5,700 | 7.0 | 0.10 | 0.34 | 13.0 |
| 3-13 | 6.7 | 7.8 | 3 | 180 | 1680 | 540 | 1150 | 10 | 1 | 62,400 | 7.0 | 0.08 | 0.81 | 11.0 |
| 13-35 | 6.6 | 7.9 | 2 | 113 | 912 | 350 | 910 | 4 | 1 | 59,600 | 15.0 | 0.05 | 0.24 | 66.0 |
| 35-150 | 5.8 | 7.4 | 58 | 213 | 1680 | 640 | 880 | 9 | 3 | 64,000 | 3.0 | 0.11 | 1.23 | 10.0 |

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Table 10

Chemical Properties of Tidal Marsh Soil Along the Atlantic Coast (Delaware)*

| Depth cm | $pH^W$ | $pH^B$ | P | K | Ca | Mg | Na | Fe | Mn | Cl | $NO_3$ | Total N | Total C | $NH_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distichlis spicata | | | | | | | | | | | | | | |
| 0-19 | 5.7 | 7.6 | 34 | 663 | 3840 | 1360 | 2410 | 66 | 2 | I.A. | 13.0 | 0.67 | I.A. | 67.0 |
| 19-29 | 6.6 | 7.8 | 42 | 338 | 1680 | 350 | 960 | 205 | 2 | 161,700 | 3.0 | 0.10 | 0.90 | 45.0 |
| 29-45 | 6.8 | 7.8 | 30 | 270 | 1620 | 360 | 880 | 81 | 2 | 11,300 | 14.0 | 0.07 | 0.52 | 7.0 |
| 45-75 | 6.7 | 7.8 | 5 | 203 | 1320 | 350 | 850 | 63 | 2 | 62,400 | 29.0 | 0.09 | I.A. | 4.0 |
| Juncus gerardi | | | | | | | | | | | | | | |
| 0-20 | 6.0 | 7.7 | 6 | 220 | 1440 | 420 | 610 | 55 | 10 | 19,900 | 15.4 | 0.20 | 1.33 | 37.8 |
| 20-30 | 5.7 | 7.6 | 8 | 225 | 1380 | 440 | 680 | 46 | 3 | 11,300 | 7.0 | 0.11 | 1.36 | 22.4 |
| 30-50 | 5.9 | 7.7 | 10 | 175 | 1080 | 350 | 570 | 15 | 1 | 19,900 | 15.4 | 0.09 | 0.80 | 11.2 |
| 50-80 | 6.3 | 7.8 | 2 | 128 | 720 | 215 | 450 | 9 | 1 | 11,300 | 4.2 | 0.12 | 0.26 | 63.0 |
| Salicornia virginica | | | | | | | | | | | | | | |
| 0-8 | 6.3 | 7.8 | 18 | 365 | 2640 | 870 | 1660 | 52 | 3 | 53,800 | 12.6 | 0.13 | 1.01 | 67.2 |
| 8-53 | 5.4 | 7.8 | 6 | 135 | 1500 | 460 | 950 | 16 | 1 | 36,900 | 7.0 | 0.06 | 0.29 | 16.8 |
| 53-70 | 5.5 | 7.8 | 6 | 138 | 1440 | 510 | 900 | 14 | 1 | 19,900 | 5.6 | 0.07 | 0.25 | 30.9 |
| 70+ | 6.3 | 7.8 | 4 | 150 | 840 | 300 | 700 | 35 | 4 | 8,600 | 8.0 | 0.09 | I.A. | 29.0 |

(Continued)

* Total N and C are in % while all other ions are in PPM.
  I.A. - Insufficient amount obtained for analysis.

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Table 10 (Concluded)

| Depth cm | pH$^W$ | pH$^B$ | P | K | Ca | Mg | Na | Fe | Mn | Cl | NO$_3$ | Total N | Total C | NH$_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spartina patens | | | | | | | | | | | | | | |
| 0-15 | 5.8 | 7.5 | 11 | 625 | 4080 | 1480 | 2840 | 35 | 4 | 70,900 | 11.0 | 1.08 | I.A. | 132.0 |
| 15-35 | 6.6 | 7.6 | 28 | 350 | 2400 | 1250 | 1680 | 26 | 1 | 209,900 | 1.4 | 0.39 | 4.51 | 65.8 |
| 35-65 | 6.3 | 7.6 | 18 | 290 | 3000 | 1380 | 2040 | 18 | 1 | 51,000 | 23.8 | 0.33 | 4.99 | 63.0 |
| 65-100 | 4.3 | 7.6 | 4 | 125 | 1440 | 490 | 980 | 38 | 1 | 31,200 | 15.4 | 0.10 | 0.69 | 32.2 |
| Phragmites communis | | | | | | | | | | | | | | |
| 0-25 | 6.8 | 7.6 | 12 | 415 | 1080 | 640 | 350 | 47 | 8 | 31,200 | 7.0 | 0.43 | 4.92 | 43.4 |
| 25-75 | 5.8 | 7.8 | 22 | 75 | 480 | 170 | 270 | 28 | 3 | 14,100 | 10.2 | 0.06 | I.A. | 44.8 |

Table 11

Chemical Properties of Tidal Marsh Soil Along the Atlantic Coast (Maine)*

| Depth cm | $pH^W$ | $pH^B$ | P | K | Ca | Mg | Na | Fe | Mn | Cl | $NO_3$ | Total N | Total C | $NH_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carex paleacea | | | | | | | | | | | | | | |
| 0-9 | 5.9 | 7.2 | 20 | 575 | 2760 | 950 | 1920 | 53 | 2 | 53,800 | 7.0 | 0.69 | 11.51 | 115.0 |
| 9-18 | 3.3 | 6.6 | 48 | 38 | 1320 | 570 | 610 | 55 | 2 | 62,400 | 8.0 | 0.30 | 3.68 | 14.0 |
| 18-28 | 5.0 | 6.7 | 55 | 115 | 1080 | 470 | 500 | 63 | 3 | 42,500 | 4.0 | 0.31 | 4.21 | 32.0 |
| 28-38 | 5.0 | 7.2 | 67 | 158 | 1500 | 700 | 510 | 59 | 3 | 82,200 | 10.0 | 0.28 | 3.53 | 83.0 |
| Juncus gerardi | | | | | | | | | | | | | | |
| 0-1 | 6.6 | 7.6 | 30 | 525 | 2760 | 1200 | 1100 | 42 | 7 | 34,000 | 11.2 | 0.52 | 5.80 | 246.4 |
| 1-3 | 6.3 | 7.0 | 20 | 450 | 2700 | 730 | 1130 | 39 | 3 | 110,600 | 12.6 | 0.40 | 4.22 | 138.6 |
| 3-6 | 5.4 | 7.4 | 34 | 388 | 3060 | 1100 | 1600 | 27 | 1 | 90,800 | 22.0 | 0.39 | 4.51 | 244.0 |
| 6-10 | 5.4 | 7.5 | 12 | 313 | 1920 | 765 | 1000 | 48 | 1 | 56,700 | 1.4 | 0.20 | 2.57 | 79.8 |
| 10-12 | 5.2 | 7.6 | 10 | 203 | 1200 | 430 | 740 | 42 | 1 | 42,500 | I.A. | 0.05 | 1.82 | I.A. |
| 12-17 | 5.3 | 7.6 | 8 | 200 | 660 | 230 | 400 | 37 | 1 | 8,500 | 15.4 | 0.10 | 0.60 | 86.8 |
| 17-35 | 4.5 | 7.4 | 8 | 325 | 1020 | 400 | 590 | 49 | 1 | 122,000 | 15.4 | 0.13 | 0.27 | 44.8 |
| 35-45 | 6.2 | 7.6 | 140 | 188 | 1560 | 470 | 650 | 32 | 2 | 28,400 | 8.4 | 0.12 | 0.16 | 5.6 |
| Spartina alterniflora (Hoy Bay) | | | | | | | | | | | | | | |
| 6-10 | 4.3 | 7.3 | 37 | 665 | 2400 | 630 | 980 | 72 | 2 | 19,900 | 11.2 | 0.36 | 2.32 | 67.2 |
| 10-24 | 5.2 | 7.6 | 95 | 565 | 2520 | 890 | 1030 | 48 | 1 | 5,700 | 8.4 | 0.34 | 2.82 | 161.0 |
| 24-37 | 4.8 | 7.4 | 94 | 565 | 2280 | 750 | 1040 | 52 | 2 | 65,200 | 14.0 | 0.34 | 2.12 | 152.6 |

(Continued)

* Total N and C are in % while all other ions are in PPM.
   I.A. - Insufficient amount obtained for analysis.

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Table 11 (Concluded)

| Depth cm | pH$^W$ | pH$^B$ | P | K | Ca | Mg | Na | Fe | Mn | Cl | NO$_3$ | Total N | Total C | NH$_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spartina alterniflora (Northeast Creek) | | | | | | | | | | | | | | |
| 0-5 | 6.6 | 7.7 | 36 | 965 | 4380 | 1700 | 1710 | 32 | 1 | 8,500 | 15.4 | 0.80 | I.A. | 225.4 |
| 5-11 | 6.3 | 7.8 | 18 | 365 | 2640 | 870 | 1660 | 52 | 3 | 53,800 | 12.6 | 0.13 | 4.61 | 67.2 |
| 11-16 | 3.7 | 7.1 | 45 | 233 | 2040 | 700 | 1180 | 71 | 8 | 62,400 | 1.4 | 0.18 | 2.62 | 42.0 |
| 16-36 | 7.0 | 7.7 | 150 | 188 | 1560 | 490 | 650 | 34 | 9 | 28,400 | 25.2 | 0.10 | 0.15 | 120.4 |
| Spartina patens | | | | | | | | | | | | | | |
| 0-3 | 5.9 | 7.5 | 41 | 888 | 4200 | 1680 | 2520 | 32 | 1 | 250,900 | 57.0 | 0.72 | 8.19 | 148.0 |
| 3-6 | 3.6 | 6.8 | 38 | 938 | 4740 | 950 | 3620 | 34 | 2 | 25,500 | 3.0 | 0.90 | I.A. | 112.0 |
| 6-11 | 4.3 | 7.0 | 32 | 675 | 3960 | 1500 | 2790 | 53 | 1 | 99,300 | 14.0 | 0.70 | 7.39 | 6.0 |
| 11-24 | 3.5 | 6.8 | 59 | 300 | 1740 | 710 | 1230 | 56 | 2 | 25,500 | 24.0 | 0.39 | 3.64 | 22.0 |
| 24-80 | 3.8 | 7.0 | 58 | 363 | 1980 | 740 | 1150 | 62 | 3 | 119,100 | 85.0 | 0.38 | 2.79 | 17.0 |

## Chemical Properties

Extractable Ca was higher than Mg. This is similar to the situation found by Coultas and Calhoun (1976) in soils in north Florida. Extractable $NH_4$ was almost always several times to an order of magnitude more abundant than $NO_3$ refelcting the generally reduced conditions in these soils. The trend toward more extractable $NH_4$ with increasing latitude was particularly evident when the Maine soils were compared to those in Delaware. In contract, $NO_3^-$ values were approximately the same at all latitudes. Generally, total nitrogen decreased with depth, but this trend was not evident in several of the Georgia soils. The correlation between total carbon and total nitrogen was high ($r = 0.94$) as shown in Figure 9. The slope was significantly different from 0 and the line can be described by the equation $Y = 13.16X = 0.64$.
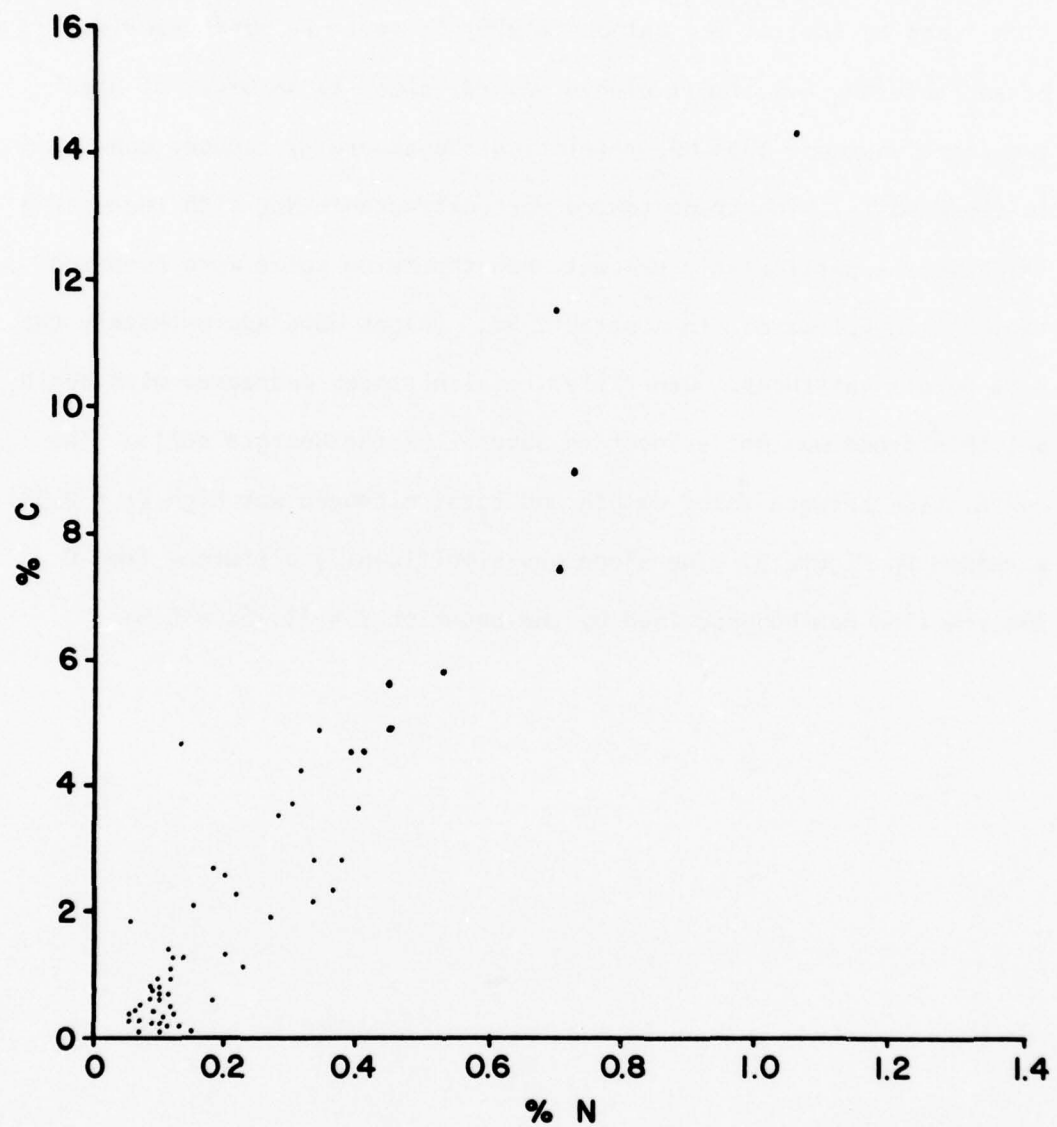
Figure 9

Total N vs. Total C in Marsh Soils from
Georgia, Delaware, and Maine

## PART IV: RESPONSE OF SALT MARSH PLANT STANDS
## TO A PULSE OF AMMONIUM NITRATE

### Introduction

Many agricultural and natural ecosystems have been shown to be limited in productivity by available nitrogen. Valiela and Teal (1974) measured an increase in plant growth in a Massachusetts _Spartina_ marsh with the addition of nitrogen. Sullivan and Daiber (1974) found a similar response in a Delaware short form _Spartina alterniflora_ marsh. Broome et al. (1973) obtained a similar enhancement in short form _S. alterniflora_ growth in North Carolina. Near the southern end of the Atlantic coast where _S. alterniflora_ dominates the intertidal wetlands, Gallagher (1974) reported a response in the short form but not in the creekbank _S. alterniflora_ stands nor in an adjacent _Juncus roemerianus_ marsh. Nitrogen availability seems to be limiting in some tidal marsh situations and not in others. There is a need for understanding nutrient regimes in areas where the less abundant plant species grow because of the dredged material disposal problems faced by the U. S. Army Corps of Engineers. The disposal of dredged material on _S. alterniflora_ marshes will raise the elevation so that the plants invading the dredged material or those most likely to be successful if planted will be the species which normally occupy only the upper fringes of the marsh.

The investigations reported here were designed to answer the following questions about the response of various salt marsh species

along the Atlantic coast from Georgia to Maine to a pulse of nitrogen added as $NH_4NO_3$.

1.  Which stands will respond by increasing in chlorophyll concentration, nitrogen content, or biomass?

2.  Are certain depths of application more effective than others in affecting the parameters listed in the question above?

3.  As indicated by rhodamine dye disappearance, which soils have the greatest water movement and hence the greatest possibility of nitrogen leaching?

## Methods

Plots were established in 17 plant stands along the coast from *Georgia to Maine* from November 1974 to May 1975. The plot design was a randomized block (4 replicates) where the treatments were nitrogen as $NH_4NO_3$ mixed with rhodamine WT dye applied below the surface, at 0-5 cm, 5-10 cm, 10-15 cm, and 15-30 cm, plus a control. A solution of $NH_4NO_3$ was prepared such that nitrogen was injected at the rate of 200 kg N/ha. Injections were made with a 50-ml syringe fitted with a specially constructed 2-mm inside diameter needle sealed at the end but with two lateral openings 5 mm behind the tip. Rhodamine WT dye was added so that 10 ml was added to each 0.10 $m^2$ plot. At least 30 individual injections were made in each plot during the injection of the volume of 150 ml of solution.

After a period of growth (Table 12), the aerial portions of the plants were harvested and the fresh and dry weight (at 60° C)

## Table 12

### Date of Establishment and Harvest
### for Nitrogen Pulse Experiments

| Site | Species | Establishment | Harvest |
|------|---------|---------------|---------|
| Georgia | Borrichia frutescens | Mar | Jun |
| | Distichlis spicata | Nov, Jan | Jun |
| | Salicornia virginica | Jan | May |
| | Spartina cynosuroides | Mar | Aug |
| | Spartina patens | Mar | Jun |
| | Sporobolus virginicus | Jan, Mar | Jun |
| Delaware | Distichlis spicata | Sept*, Jan | Jan, Jun |
| | Juncus gerardi | Sept*, Jan | May, Aug |
| | Salicornia virginica | Mar | Jun |
| | Spartina patens | Mar | Aug |
| Maine | Juncus gerardi | May | Aug |
| | Spartina alterniflora | May | Aug |
| | Spartina patens | May | Aug |

* 1974; all other dates 1975.

determined. Chlorophyll was extracted in acetone (Strickland and
Parsons, 1968), and the concentration of chlorophyll A and B was deter-
mined using the equations of Arnon (1949). Two cores were taken in
each plot to a depth of 35 cm with a piston corer. Both were section-
ed 0-5, 5-10, 10-15, and 13-35 cm. One was washed over a 1-mm sieve
with seawater and the biomass of the underground macro-organic matter
(MOM) determined. The second core was split in half. One half was
freeze-dried and ground to pass a 40-mesh sieve. Total nitrogen was
determined on the aerial plant material, MOM, and the freeze-dried
soil by the Kjeldahl method. Rhodamine was extracted from the other
half of the split core. The core segment was placed in a blender with
200 ml of water and the sample dispersed for 2 minutes. The volume
was brought up to 250 ml. A 15-ml aliquot was removed and spun for
5 minutes in a table-top centrifuge. The rhodamine WT concentration
in the supernate was determined by fluorometry. All statistical
methods are described in Sokal and Rohlf (1969).

## Results and Discussion

The results of the rhodamine WT dye studies are shown in Tables
13, 14, 15. These data show that the leachable dye did not move away
from the injection site rapidly in any of the soils. Since the dye is
more likely to move than the inorganic nitrogen, the authors were re-
assured that the nitrogen was not leached before it could be absorbed.
Comparison of the two D. spicata experiments in Georgia (Table 13)
indicates most of the dye was lost from the one established in November

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# Table 13

## Relative Rhodamine WT Concentration at 4 Depths in Marsh Soils in Georgia

### Where the Dye Was Injected at 1 of 4 Depths

| Species | Time Format* | 0 - 5 | | | | 5 - 10 | | | | 10 - 15 | | | | 15 - 35 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Depth, cm | | | | | | | | | | | | | | | |
| | | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 |
| Borrichia frutescens | a | 192 | 96 | 143 | 68 | 103 | 160 | 41 | 163 | 44 | 42 | 47 | 76 | 16 | 17 | 9 | 208 |
| Distichlis spicata | b | 3 | 3 | 4 | 3 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 3 | 2 | 4 | 3 |
| Distichlis spicata | c | 297 | 4 | 3 | 3 | 72 | 149 | 45 | 16 | 34 | 14 | 40 | 4 | 22 | 3 | 5 | 13 |
| Salicornia virginica | d | 168 | 40 | 19 | 68 | 98 | 97 | 159 | 127 | 174 | 108 | 217 | 149 | 40 | 36 | 73 | 95 |
| Spartina cynosuroides | e | 14 | 26 | 3 | 9 | 7 | 4 | 4 | 5 | 4 | 14 | 42 | 38 | 4 | 4 | 394 | 174 |
| Spartina patens | a | 115 | 69 | 55 | 28 | 29 | 339 | 166 | 242 | 8 | 54 | 44 | 54 | 2 | 8 | 60 | 150 |
| Sporobolus virginicus | b | 97 | 56 | 4 | 3 | 45 | 39 | 7 | 2 | 52 | 114 | 85 | 68 | 26 | 17 | 28 | 534 |

\* a - applied in March - sampled in June  
   b - applied in November - sampled in June  
   c - applied in January - sampled in June  
   d - applied in January - sampled in May  
   e - applied in March - sampled in August

Table 14

Relative Rhodamine WT Concentration at 4 Depths in Marsh Soils in Delaware

Where the Dye Was Injected at 1 of 4 Depths

| Species | Time Format* | Depth, cm | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 - 5 | | | | 5 - 10 | | | | 10 - 15 | | | | 15 - 35 | | | |
| | | Sample Depth, cm | | | | | | | | | | | | | | | |
| | | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 |
| Distichlis spicata | a | 258 | 277 | 8 | 2 | 28 | 160 | 40 | 3 | 9 | 111 | 182 | 52 | 9 | 18 | 110 | 452 |
| Distichlis spicata | b | 112 | 26 | 11 | 4 | 43 | 233 | 151 | 2 | 5 | 36 | 151 | 4 | 65 | 25 | 14 | 66 |
| Distichlis spicata | c | 67 | 54 | 6 | 4 | 182 | 36 | 6 | 5 | 12 | 39 | 54 | 5 | 48 | 54 | 29 | 347 |
| Juncus gerardi | d | 112 | 343 | 2 | 2 | 10 | 16 | 4 | 720 | 8 | 25 | 4 | 181 | 4 | 6 | 30 | 3 |
| Juncus gerardi | e | 638 | 277 | 6 | 5 | 51 | 274 | 72 | 5 | 21 | 138 | 638 | 326 | 16 | 14 | 22 | 138 |
| Juncus gerardi | f | 81 | 6 | 5 | 3 | 8 | 11 | 6 | 2 | 10 | 43 | 30 | 19 | 7 | 8 | 67 | 6 |
| Spartina patens | g | 140 | 50 | 6 | 11 | 17 | 49 | 4 | 4 | 7 | 249 | 289 | 54 | 4 | 20 | 8 | 140 |
| Salicornia virginica | h | 788 | 590 | 172 | 22 | 67 | 898 | 809 | 97 | 29 | 316 | 293 | 22 | 29 | 21 | 13 | 167 |

* a - applied in September - sampled in January  
  b - applied in January - sampled in June  
  c - applied in September - sampled in June  
  d - applied in September - sampled in May  
  e - applied in January - sampled in May  
  f - applied in January - sampled in August  
  g - applied in March - sampled in August  
  h - applied in March - sampled in June

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Table 15

Relative Rhodamine WT Concentration at 4 Depths in Marsh Soils in Maine

Where the Dye Was Injected at 1 of 4 Depths in May and Sampled in August

| Species | Depth, cm | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 - 5 | | | | 5 - 10 | | | | 10 - 15 | | | | 15 - 35 | | | |
| | Sample Depth, cm | | | | | | | | | | | | | | | |
| | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 | 0-5 | 5-10 | 10-15 | 15-35 |
| Juncus gerardi | 34 | 60 | 25 | 5 | 19 | 106 | 11 | 3 | 15 | 126 | 618 | 69 | 29 | 33 | 40 | 80 |
| Spartina alterniflora | 265 | 97 | 5 | 2 | 119 | 672 | 33 | 19 | 56 | 359 | 152 | 3 | 68 | 22 | 5 | 68 |
| Spartina patens | 202 | 94 | 4 | 2 | 5 | 18 | 4 | 4 | 2 | 33 | 92 | 2 | 6 | 40 | 45 | 85 |

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and harvested in June while much remained when the dye was injected in January. This difference was probably primarily a function of the longer period the dye was exposed to leaching in the plots established in November.

Tables 16, 17, 18 show the results of nutrient enrichment on the aerial biomass of the plants studied. The only clear enhancement in Georgia was in Salicornia virginica ($\alpha = 0.01$). In Delaware, J. gerardi responded positively to the nitrogen addition in both experiments ($\alpha = 0.05$). The S. virginica enrichment also gave positive results in Delaware. None of the enrichment studies in Maine gave positive results. The lack of response in Maine was not unexpected in view of the high ammonium ion levels measured in the soil (Part III). Thus, along the coast, biomass produced was limited by the available nitrogen in only a few instances. Gallagher (1975) earlier found a response in high marsh S. alterniflora but none in J. roemerianus or creekbank S. alterniflora.

Some of the plants which had positive biomass responses and several which did not were tested for nitrogen content to see if added nutrient would change the quality of detritus entering the estuarine food web from these plant stands. Table 19 shows the results of these analyses. The J. gerardi in Delaware which showed a biomass response to nitrogen also exhibited a nitrogen content response. The S. virginicus stand in Georgia did not show a response in biomass, but the nitrogen content of the treated plants was 1.7 that of the control plants.

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## Table 16

Mean Standing Crop of Live and Dead Plants (g dry weight/M$^2$) of Georgia

Marsh Plants Receiving a 200 kg/ha  Pulse of Nitrogen at 4 Depths

| Depth of Treatment (cm) | Borrichia frutescens a | | | Distichlis spicata b | | | Sporobolus virginicus e | | |
|---|---|---|---|---|---|---|---|---|---|
| | Live | Dead | Total | Live | Dead | Total | Live | Dead | Total |
| Control | 428(266)* | 136(125) | 564(290) | 298(66) | 332(102) | 630(166) | 390(76) | 76(64) | 466(128) |
| 0-5 | 714(316) | 84(52) | 798(268) | 532(204) | 336(116) | 868(246) | 266(110) | 56(44) | 322(78) |
| 5-10 | 606(294) | 134(94) | 740(356) | 604(192) | 336(136) | 940(316) | 238(180) | 40(22) | 278(192) |
| 10-15 | 600(372) | 114(32) | 714(354) | 548(192) | 260(76) | 808(252) | 342(174) | 30(12) | 372(172) |
| 15-35 | 662(328) | 68(28) | 730(336) | 480(54) | 230(150) | 710(132) | 472(154) | 24(2) | 496(158) |

| Depth of Treatment (cm) | Spartina cynosuroides d | | | Spartina patens a | | | Salicornia virginica c |
|---|---|---|---|---|---|---|---|
| | Live | Dead | Total | Live | Dead | Total | Total |
| Control | 1428.8(686.8) | 880.8(96.4) | 2309.6(597.2) | 924.6(363.2) | 458.0(109) | 1382.6(258) | 106(20) |
| 0-5 | 1563.6(1414.4) | 1082.4(358) | 2646.0(1763.6) | 826.6(221.8) | 3506.0(96) | 4332.6(302) | 660(230) |
| 5-10 | 1345.6(574.4) | 1044.8(484) | 2390.4(678.4) | 1172.6(223.8) | 359.0(109) | 1531.6(272) | 836(340) |
| 10-15 | 1333.6(434.8) | 1423.2(560) | 2756.8(991.2) | 1543.0(183.0) | 302.6(221.6) | 1845.6(350) | 590(156) |
| 15-35 | 2342.4(1250) | 908.4(636) | 3250.8(1620) | 1220 (906.6) | 364.6(119.6) | 1584.6(1132) | 526(66) |

* numbers in parentheses are S.E. values where N=4

a  March enrichment – June harvest      d  March enrichment – August harvest
b  January enrichment – July harvest      e  November enrichment – June harvest
c  January enrichment – May harvest

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## Table 17

### Mean Standing Crop of Live and Dead Plants (g dry weight/M$^2$) of Delaware

### Marsh Plants Receiving a 200 kg/ha Pulse of Nitrogen at 4 Depths

| Depth of Treatment (cm) | a Distichlis spicata | | | b Distichlis spicata | | | f Salicornia virginica | e Juncus gerardi | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Live | Dead | Total | Live | Dead | Total | Total | Live | Dead | Total |
| Control | 462(60)* | 470(88) | 932(52) | 462(60) | 470(88) | 932 | 872(56) | 2.0(.6) | 120(66) | 122(66) |
| 0-5 | 492(156) | 404(8) | 896(158) | 414(146) | 272(136) | 686 | 1062(128) | 288(80) | 72(78) | 360(158) |
| 5-10 | 572(76) | 516(228) | 1088(260) | 592(292) | 352(198) | 944 | 1076(172) | 334(72) | 102(36) | 436(94) |
| 10-15 | 570(14) | 412(42) | 982(52) | 296(120) | 396(124) | 692 | 1082(182) | 382(56) | 152(88) | 534(126) |
| 15-35 | 654(390) | 496(112) | 1150(38) | 396(302) | 436(192) | 832 | 1014(46) | 372(72) | 180(170) | 552(94) |

| Depth of Treatment (cm) | c Juncus gerardi | | | d Phragmites communis | | | d Spartina patens | | |
|---|---|---|---|---|---|---|---|---|---|
| | Live | Dead | Total | Live | Dead | Total | Live | Dead | Total |
| Control | 60(8) | 50(14) | 111(22) | 1381(536) | 2654(691) | 4035(610) | 742(98) | 520(176) | 1262(108) |
| 0-5 | 306(72) | 152(58) | 458(44) | 1328(697) | 2735(649) | 4063(1110) | 632(220) | 554(92) | 1186(264) |
| 5-10 | 326(132) | 128(36) | 454(134) | 2054(1269) | 1948(637) | 4002(1450) | 744(352) | 652(172) | 1396(304) |
| 10-15 | 312(54) | 160(58) | 472(74) | 1475(1137) | 1574(926) | 3049(1361) | 632(180) | 652(190) | 1284(308) |
| 15-35 | 310(92) | 160(56) | 470(120) | 2163(316) | 2305(1018) | 4468(817) | 628(286) | 600(138) | 1228(236) |

* numbers in parentheses are S.E. values where N=4

a   September enrichment - June harvest  
b   January enrichment - June harvest  
c   January enrichment - May harvest  
d   March enrichment - August harvest  
e   September enrichment - January harvest  
f   March enrichment - June harvest

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Table 18

August Mean Standing Crop of Live and Dead Plants (g dry weight/M$^2$) of Maine Marsh Plants

Receiving a 200 kg/ha Pulse of Nitrogen at 4 Depths in May

| Depth of treatment (cm) | Juncus gerardi | | | Spartina alterniflora | | | Spartina patens | | |
|---|---|---|---|---|---|---|---|---|---|
| | Live | Dead | Total | Live | Dead | Total | Live | Dead | Total |
| Control | 90(74)* | 506(126) | 596(158) | 644(412) | 52(38) | 696(412) | 742(308) | 276(190) | 1018(486) |
| 0-5 | 72(20) | 664(132) | 736(144) | 620(192) | 22(20) | 642(192) | 608(266) | 336(56) | 944(242) |
| 5-10 | 104(148) | 672(130) | 776(188) | 480(286) | 170(96) | 650(220) | 914(296) | 480(336) | 1394(596) |
| 10-15 | 156(140) | 494(28) | 650(154) | 574(170) | 60(118) | 634(224) | 736(310) | 524(174) | 1260(450) |
| 15-35 | 100(32) | 544(110) | 644(138) | 636(324) | 64(28) | 700(300) | 784(254) | 284(58) | 1068(224) |

* numbers in parentheses are S.E. values where N=4

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Table 19

Nitrogen Content of Live Plants and Their Respective Standing Dead Communities

After Receiving a 200 kg/ha Pulse of Nitrogen (means expressed as % of dry weight)

| | Live | | Dead | |
|---|---|---|---|---|
| | Control | Treated | Control | Treated |
| Sporobolus virginicus (GA) | (0.89) | (1.53)a | (0.84) | (1.16)a |
| Spartina cynosuroides (GA) | 1.27 | 1.15 | 0.91 | 0.96 |
| Juncus gerardi (DL) | 1.26 | 1.51* | 1.68 | 1.89 |
| Spartina alterniflora (ME) | 1.24 | 1.37 | 1.31 | 1.30 |
| Spartina patens (ME) (DL) | 1.22 0.94 | 1.27 0.97 | 1.11 0.87 | 0.99 0.93 |
| Phragmites communis (DL) | 1.59 | 1.23 | 1.28 | 1.38 |

* F distribution value of numbers underlined found to be significant (0.05).

a F distribution value of numbers in parentheses found to be highly significant (0.005).

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Since at harvest time it was noted that the chlorophyll content appeared to vary between treatments, the samples were analyzed for chlorophyll A and B (Tables 20, 21, 22). In Georgia the B. frutescens treatments were higher than the control, although biomass differences were not detected. No other statistical differences in chlorophyll content were noted although visual differences were evident. In Delaware, differences in chlorophyll were statistically significant only in the D. spicata treatment and no consistent shifts in the A/B ratio were noted. As with the other parameters measured in the Maine experiments, no increase in chlorophyll or shift in A/B ratio was observed.

Nitrogen may be limiting productivity or affecting plant nutrient quality for grazers or the members of the detrital food web. The evidence from these studies is that this may be true in Georgia for S. virginica, S. virginicus, and B. frutescens but not for the D. spicata, S. cynosuroides, or S. patens stands evaluated. Earlier studies indicated a large response in short S. alterniflora, a possible slight response in creekbank S. alterniflora as evidenced by a change in color in infrared photographs, and no response in J. roemerianus (Gallagher, 1975).

The Delaware experiments showed evidence of enhancement in the J. gerardi, S. virginica, and D. spicata but none in the stands of P. communis or S. patens. Earlier work by Sullivan and Daiber (1974) indicated short form S. alterniflora growth could be enhanced by adding nitrogen.

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Table 20

Chlorophyll A (mg chlorophyll/g fresh weight) and A/B Fraction in Live Marsh Plants

from Georgia. Treated Plants Received 200 kg/ha Nitrogen at 1 of 4 Depths

| Depth of treatment (cm) | Borrichia frutescens [a] | | Distichlis spicata [b] | | Salicornia virginica [c] | | Spartina cynosuroides [d] | | Spartina patens [a] | | Sporobolus virginicus [e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | A/B | A | A/B | A | A/B | A | A/B | A | A/B | A | A/B |
| Control | 0.085 (.021)* | 2.39 (.55) | 0.480 (.132) | 2.51 (.12) | 0.152 (.066) | 14.04 (19.44) | 0.560 (.320) | 2.17 (.20) | 0.634 (.094) | 2.29 (.05) | 0.320 (.072) | 2.26 (.12) |
| 0-5 | 0.186 (.018) | 2.43 (.16) | 0.602 (.086) | 2.51 (.02) | 0.189 (.072) | 6.37 (.51) | 0.550 (.062) | 2.12 (.15) | 0.734 (.356) | 2.25 (.04) | 0.504 (.100) | 2.17 (.23) |
| 5-10 | 0.143 (.020) | 2.30 (.04) | 0.467 (.159) | 2.33 (.04) | 0.230 (.022) | 2.45 (1.94) | 0.473 (.160) | 2.20 (.05) | 0.615 (.109) | 2.31 (.27) | 0.303 (.140) | 1.87 (.23) |
| 10-15 | 0.176 (.009) | 2.63 (.29) | 0.750 (.198) | 2.40 (.13) | 0.234 (.133) | 2.85 (2.23) | 0.837 (.169) | 2.12 (.11) | 0.750 (.132) | 2.28 (.16) | 0.349 (.160) | 2.13 (.26) |
| 15-35 | 0.130 (.068) | 3.34 (.79) | 0.494 (.138) | 2.19 (.33) | 0.241 (.068) | 3.52 (1.85) | 0.400 (.243) | 2.14 (.11) | 0.546 (.232) | 2.24 (.10) | 0.368 (.153) | 2.16 (.10) |

* numbers in parentheses are S.E. values where N=4
a  March enrichment – June harvest
b  January enrichment – July harvest
c  January enrichment – May harvest
d  March enrichment – August harvest
e  November enrichment – June harvest

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Table 21

Chlorophyll A (mg chlorophyll/g fresh weight) and A/B Fraction in Live Marsh Plants from Delaware.

Treated Plants Received 200 kg/ha Nitrogen at 1 of 4 Depths

| Depth of Treatment (cm) | Distichlis spicata a | | Distichlis spicata b | | Juncus gerardi e | | Juncus gerardi c | | Phragmites communis d | | Salicornia virginica f | | Spartina patens d | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | A/B | A | A/B | A | A/B | A | A/B | A | A/B | A | A/B | A | A/B |
| Control | 0.430 (.106)* | 2.22 (.29) | 0.430 (.106) | 2.22 (.29) | NONE | | NONE | | 0.482 (.191) | 2.52 (.17) | 0.133 (.012) | 2.73 (.25) | 0.175 (.083) | 2.37 (.33) |
| 0-5 | 0.729 (.224) | 2.24 (.27) | 0.584 (.149) | 1.94 (.04) | 0.451 (.109) | 3.24 (.44) | 0.560 (.226) | 2.13 (.74) | 0.546 (.271) | 2.73 (.30) | 0.140 (.019) | 2.44 (.49) | 0.388 (.110) | 2.37 (.16) |
| 5-10 | 0.700 (.080) | 2.09 (.16) | 0.838 (.018) | 2.24 (.11) | 0.638 (.284) | 4.91 (5.18) | 0.706 (.112) | 2.61 (.52) | 0.444 (.140) | 2.46 (.23) | 0.137 (.016) | 2.34 (.80) | 0.188 (.040) | 2.34 (.02) |
| 10-15 | 0.892 (.211) | 2.26 (.15) | 0.720 (.141) | 2.05 (.26) | 0.600 (.098) | 2.81 (.19) | 0.587 (.137) | 3.01 (.99) | 0.536 (.307) | 1.43 (1.24) | 0.140 (.034) | 2.82 (.23) | 0.250 (.078) | 2.49 (.36) |
| 15-35 | 0.757 (.131) | 2.06 (.23) | 1.728 (1.360) | 4.13 (2.71) | 0.412 (.125) | 2.01 (.25) | 0.570 (.182) | 2.39 (.68) | 0.452 (.296) | 2.72 (.11) | 0.116 (.008) | 2.50 (.54) | 0.221 (.060) | 1.69 (1.15) |

* numbers in parentheses are S.E. values where N=4

a  September enrichment - June harvest
b  January enrichment - June harvest
c  January enrichment - May harvest
d  March enrichment - August harvest
e  September enrichment - May harvest
f  March enrichment - June harvest

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Table 22

Augmented Chlorophyll A (mg chlorophyll/g fresh weight) and A/B Fraction in Live Marsh
Plants from Maine Receiving a 200 kg/ha Pulse of Nitrogen at 4 Depths in May

| Depth of Treatment (cm) | Juncus gerardi | | Spartina alterniflora | | Spartina patens | |
|---|---|---|---|---|---|---|
| | A | A/B | A | A/B | A | A/B |
| Control | 0.364(.255)* | 2.87(.90) | 0.691(.320) | 4.23(3.06) | 0.494(.244) | 3.20(1.48) |
| 0-5 | 0.474(.210) | 2.23(.85) | 0.435(.329) | 2.79(.23) | 0.546(.178) | 2.62(.10) |
| 5-10 | 0.278(.090) | 2.22(.58) | 0.391(.219) | 2.69(.12) | 0.509(.171) | 2.69(.06) |
| 10-15 | 0.388(.125) | 2.18(.33) | 0.363(.236) | 2.10(.60) | 0.585(.129) | 3.48(1.56) |
| 15-35 | 0.510(.362) | 1.82(.90) | 0.448(.170) | 2.60(.09) | 0.699(.249) | 2.44(.11) |

* numbers in parentheses are S.E. values where N=4

The number of replicates chosen in these experiments was based on similar studies conducted in Georgia on _S. alterniflora_ and _J. roemerianus_ (Gallagher, 1975). Variability in several of the species in the study reported in this part of the report proved higher than those studied earlier. If the response of one of the more variable species (_S. alterniflora_ in Maine, for example) becomes of immediate interest, intensive studies should be initiated.

## PART V:   SALT MARSH PLANT GROWTH ON THREE TYPES
## OF DREDGED MATERIAL

### Introduction

During the past two decades large acreages of natural coastal eco-
systems have been destroyed by industrial and recreational development.
Recently there have been many initiatives to either restore perturbated
natural systems or to create new areas to substitute for areas which
cannot be restored.  The U. S. Army Corps of Engineers has been very
interested in developing techniques to vegetate dredged material
islands.  A problem arises when it is desired to create a marsh on a
specific dredged material.  Soil testing techniques are not yet avail-
able which would enable the prediction of success of each of the several
dozen potential species on the various types of dredged material which
may be found at numerous coastal environments.

This study was designed to examine the growth of several species
of marsh plants on three widely different types of dredged material from
the Georgia coast and to compare several methods which could serve as
bioassay techniques for testing the ability of various plant species
to grow in specific dredged material situations.

### Methods

Three types of dredged material were selected which had diverse
properties.  The first was a coarse sandy material from nearly fresh water;
the second was a mixture of fine sand, lumps of silt, and clay from brackish

water; and the third was a silt and clay mixture from a saline river. (See Part III for a more detailed description of the collection sites and the materials.) These gave the extremes which are likely to be encountered in the southeast Atlantic coast.

## Greenhouse Experiment

In the first experiment, cylindrical plastic trash cans 32.5 cm in diameter and 35.6 cm high were filled with the dredged material and placed in a greenhouse. The greenhouse used was glass with mechanical air circulation but without an evaporative cooler or air conditioning. The use of whitewash and shades over the glass reduced the inside light approximately 50% but reduced internal heating to usually less than $5°C$ above ambient. This range is well within the conditions experienced in stands of marsh plants. One set (one each of the three types of dredged material) of tubs was left unplanted while others were planted with sprigs of freshly dug plant material from nearby marshes between 24 and 31 July 1974 (Table 23). Each tub was planted at 1/10 of the natural stand density. Each combination of plant and substrate was established in triplicate. Wells made of 1.27-cm-diameter PVC tubing were placed vertically to a depth of 10 and 25 cm in each container. During the study the water in the wells was tested for pH and salinity. The containers of plants were watered with fresh water as needed from above (to wash accumulated salt on the plants back to the soil) to keep the soil near field capacity above the 10-cm depth and saturated below that. These soil conditions approximated those near mean low water in the natural marsh.

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Table 23

Plant Species Used in the Greenhouse and

Dike Studies of Substrate Response

| Species planted | Greenhouse study | Dike study lower level | Dike study upper level |
|---|---|---|---|
| None | X | | |
| Borrichia frutescens | X | X | X |
| Distichlis spicata | X | X | |
| Iva frutescens | X | | |
| Spartina cynosuroides | X | | |
| Spartina patens | X | | |
| Sporobolus virginicus | | | X |

Particle density was determined in August and soil bulk density profiles were measured in July 1974 and in March 1976. Particle density was calculated from weights obtained when soil displaced water from a volumetric flask. Bulk density was obtained by weighing dried cores of known volume. Soil carbon was determined with a Leco Carbon Determinator according to the method described by Gallagher, Plumley, and Perkins (in press). Soils were allowed to dry to the point where no water was standing in the shallow wells and water infiltration was measured using a field rainfall simulator as a water source. The device was built from a 10-cm section of 12-cm-diameter PVC pipe. A solid bottom was perforated with 21 gauge hypodermic needles. A similar size diameter aluminum pipe with a sharp edge was pushed into the soil so that the outlet pipe was at ground level. The PVC pipe was placed above the aluminum section and water added to the PVC tube from a separatory funnel suspended above it. A constant head was maintained in the PVC tube so that the drop size and flow rate remained constant and produced a flow rate of 2.5 cm per pour. Runoff was collected in a bottle placed at the outlet pipe. Infiltration was calculated as the difference between water added and runoff. Samples of the dredged material were air-dried and subjected to analysis according to the standard methods used by the Plant and Soil Testing Laboratory at the University of Georgia. Total nitrogen was determined by Kjeldahl analysis.

Stem counts were taken frequently during the course of the experiment. Chlorophyll content of the S. patens and D. spicata growing on

the three substrates was determined in July and August 1975 by the method described by Arnon (1949). Aerial and underground biomass were determined upon termination of the experiment in March 1976.

## Field Experiment

A second experiment with the three types of dredged material was established in the field in March 1975. The purpose of this study was to more closely simulate the actual situation where a dredged material would be placed in the intertidal zone in a marsh.

Triplicate trash containers, like those used in the previous experiment, were filled with each of the three types of dredged material and buried in an intertidal dredged material pile so that they were inundated by spring tides. Holes were punched in the bottom of the plastic trash containers in order to allow drainage. Freshly dug sprigs of D. spicata were planted in each container.

In order to test for the effect of reduced drainage due to the containers, pits were dug at the same level; the vertical sides were lined with polyethylene; and triplicate pits were filled with the three types of dredged material. These pits had approximately twice the area of the trash containers. Half of each pit was planted with D. spicata and the other half with B. frutescens. A second series of pits were similarly dug and filled at a higher elevation which was subject to only the highest spring tides. Half of each pit was planted with S. virginicus and half with B. frutescens.

Soil pH was determined; soil bulk density profiles taken; rainfall infiltration measured; and in March 1976 the experiment terminated.

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Aerial samples of plants were harvested and dried to a constant weight at 60°C. Cores of the soil were taken from each plot for root biomass determination and soil carbon evaluation. All statistical proce res used were outlined by Sokal and Rohlf (1969).

## Results and Discussion

### Greenhouse Study

Stem density. In terms of numbers of live stems per square meter, D. spicata reached maximum growth when on silt and clay (Figures 10, 11, 12). D. spicata was relatively successful on the other two sub-strates as well. S. patens experienced its most successful growth on sand and clay with relatively good growth on sand. B. frutescens, I. frutescens, and S. cynosuroides grew only on sand, but not with any significant success. Since these environmental conditions simulated the low intertidal zone, the poor aeration which existed in the fine-textured soils was probably the cause of the failure of B. frutescens and I. frutescens to grow well under these conditions. These plants grow high in the intertidal zone in natural marshes. Whether the problem is one of low oxygen directly or the accumulation of toxic substances ($H_2S$, for example) is purely a matter of speculation.

Biomass. Aerial and root biomass data (Table 24) based on the March 1976 harvest paralleled the stem density counts. Distichlis spicata achieved its greatest biomass on silt and clay, while S. patens had the greatest biomass on sand and clay. Borrichia fru-tescens, I. frutescens, and S. cynosuroides showed live aerial

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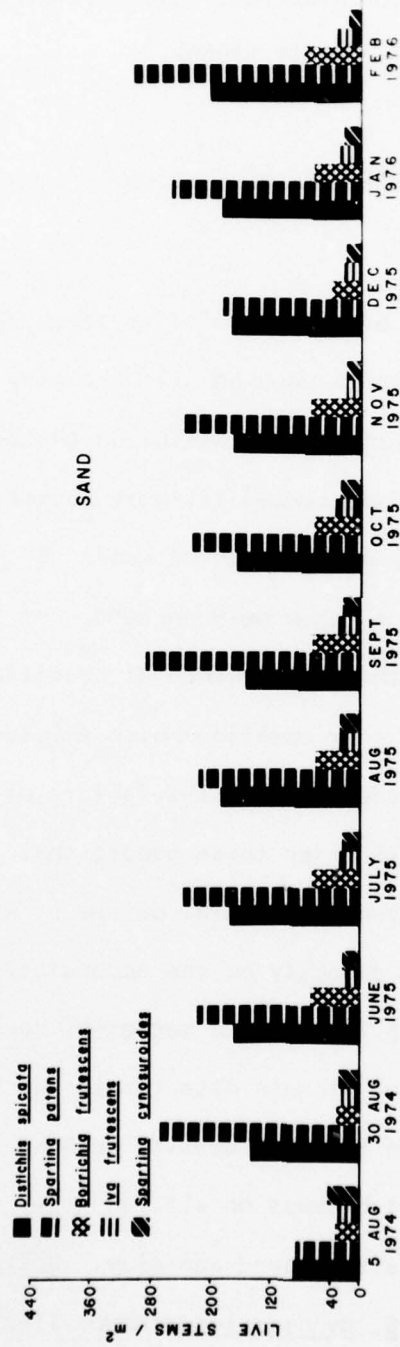
Figure 10

Live Stems per m$^2$ of Various Marsh Plants Grown in the Greenhouse

on a Sandy Dredged Material Held within Trash Containers
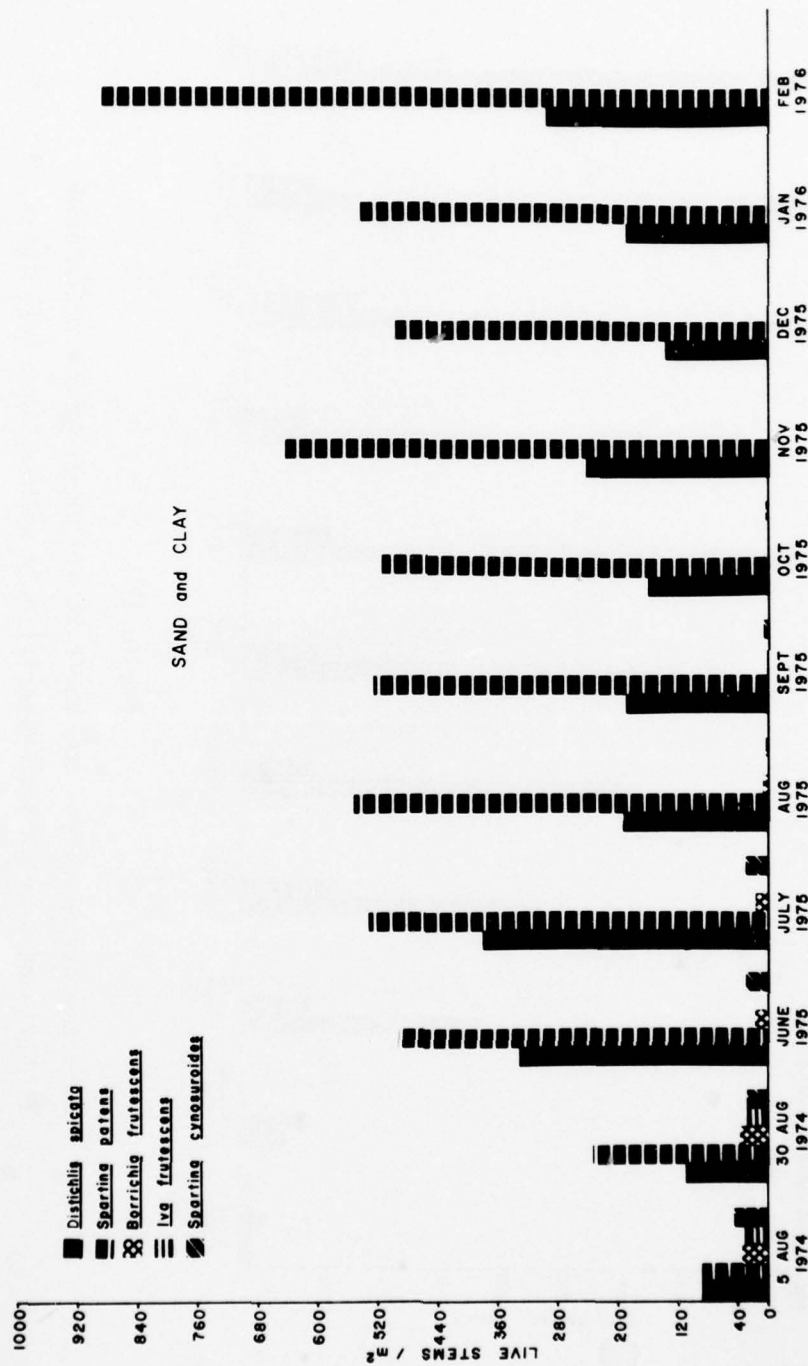
SAND and CLAY

Figure 11

Live Stems per m$^2$ of Various Marsh Plants Grown in the Greenhouse
on a Sand and Clay Dredged Material Held within Trash Containers

Figure 12

Live Stems per m² of Various Marsh Plants Grown in the Greenhouse
on Silt and Clay Dredged Material Held within Trash Containers

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Table 24

Aerial and Root Biomass ($g/m^2$)* of Greenhouse Plant Material Based on March 1976 Harvest

| Species | Silt and Clay | | | Sand | | | Sand and Clay | | |
|---|---|---|---|---|---|---|---|---|---|
| | Live Stems | Dead Stems | Roots | Live Stems | Dead Stems | Roots | Live Stems | Dead Stems | Roots |
| Distichlis spicata | 257.33 | 22.40 | 213.47 | 22.70 | 39.53 | 64.05 | 53.33 | 103.00 | 168.60 |
| Spartina patens | 68.35 | 47.93 | 67.40 | 22.67 | 57.73 | 147.37 | 246.00 | 90.00 | 272.57 |
| Borrichia frutescens | 0.00 | 16.23 | 15.07 | 65.00 | 20.97 | 48.17 | 0.00 | 20.73 | 8.17 |
| Iva frutescens | 0.00 | 27.10 | 74.00 | 25.00 | 4.20 | 21.10 | 0.00 | 1.07 | 1.70 |
| Spartina cynosuroides | 0.00 | 43.30 | 67.13 | 0.67 | 101.13 | 79.63 | 0.00 | 217.67 | 154.57 |

* Dry weight

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biomass only on sand in March. Even though there were relatively few live stems with a correspondingly low biomass, the root biomass for S. cynosuroides in all three substrates appeared to be significant. Results of analysis of variance (Table 25) showed that no significant difference occurred in total aerial biomass for any species on the three substrates tested except for the woody plant B. frutescens where the greatest biomass was on the sand and the other two substrates were lower. There was, however, a significant difference in the biomass of live D. spicata among the three substrates. A Student-Newman-Keuls (SNK) range multiple test indicated the growth was best on the silt and clay while the other two substrates did not differ.

Root biomass did not differ significantly among the three substrates for S. cynosuroides and D. spicata; however, differences did occur among S. patens, B. frutescens, and I. frutescens. Root biomass in S. patens was greatest in the sand and clay, less on the sand, and least on the silt and clay. This may be expected because the natural haibtat of S. patens in Georgia is a high sandy marsh or a low dune area. The sand-clay substrate had high fertility while still retaining good drainage. Borrichia frutescens, which normally grows at the upper fringes of the marsh, produced the most root growth in the sand soil. Surprisingly, I. frutescens, which also lives on the marsh fringe, produced a large amount of roots in the silt and clay dredged material.

Chlorophyll. Chlorophyll content of D. spicata and S. patens was significantly higher on the silt and clay than on the other two

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Table 25

Results of Analysis of Variance of Aerial and Root Biomass

from Plants Grown on Three Substrates in the Greenhouse Study

| Species | Total Aerial Biomass | Comparison Live Aerial Biomass F-values | Root Biomass |
|---|---|---|---|
| Borrichia frutescens | 7.810 * | 1.293 N.S. | 11.450 ** |
| Distichlis spicata | 2.770 N.S. | 5.420 * | 1.274 N.S. |
| Iva frutescens | 1.490 N.S. | 1.749 N.S. | 12.320 ** |
| Spartina cynosuroides | 4.411 N.S. | 3.496 N.S. | 0.815 N.S. |
| Spartina patens | 3.503 N.S. | 1.606 N.S. | 9.514 * |

*      Significant at 0.05 level
**     Significant at 0.01 level
N.S.   Not significant

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substrates (Table 26). This was probably due to the higher nitrogen content of this material. The highest chlorophyll content of plants grown on sand was observed in D. spicata. The above two species were selected for chlorophyll analysis because it was only in these two species that significant growth occurred on all three substrates.

Bulk density. Bulk densities for substrates with and without plants appear in Table 27. A comparison of the bulk density for the combined values for each substrate at harvest with the initial values shows an increase in bulk density for silt and clay (0.390 to 0.443), a decrease in sand (1.503 to 1.414), and a decrease in sand and clay (1.494 to 1.335). Results of the Student's t-test showed that the above differences are significant. All comparisons with significant t-values are listed in Table 28. Results of particle density determinations are as follows: sand, $2.650 \pm 0.200$ g/cm$^3$; silt and clay, $2.693 \pm 0.343$ g/cm$^3$; and sand and clay, $2.456 \pm 0.060$ g/cm$^3$.

Carbon. The results of the carbon analyses are listed (Table 29). A comparison of means utilizing the Student's t-test showed the following significant differences: initial sand and clay higher than S. patens on sand and clay (t = 3.500); initial silt and clay higher than D. spicata on silt and clay, 1976 (t = 4.243); S. cynosuroides on sand and clay, 1976, higher than control, 1976, sand and clay (t = 2.460); I. frutescens on sand, 1976, higher than control sand, 1976 (t = 3.040); and initial sand higher than control sand, 1976 (t = 43.412). All other comparisons resulted in t-values which were not significant. The reasons for some of the apparent discrepancies in

Table 26

Results of the SNK Range Test on Analysis of Variance of Chlorophyll Values

for Spartina patens and Distichlis spicata on Three Types of

Dredged Material in the Greenhouse Study

| Species | Substrate | $\overline{X}$ | |
|---|---|---|---|
| Spartina patens | Sand | 0.330 | ▭ |
| Spartina patens | Sand and clay | 0.431 | ▯ |
| Distichlis spicata | Sand and clay | 0.438 | ▯ |
| Distichlis spicata | Sand | 0.868 | ▯ |
| Distichlis spicata | Silt and clay | 1.164 | ▯ |
| Spartina patens | Silt and clay | 1.246 | |

NOTE: Collections were on 22 July and 25 August 1975.
Mean chlorophyll values in milligrams chlorophyll per gram tissue.
Bars connect rates which are indistinguishable by the Student-
Newman-Keuls range test.

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MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A
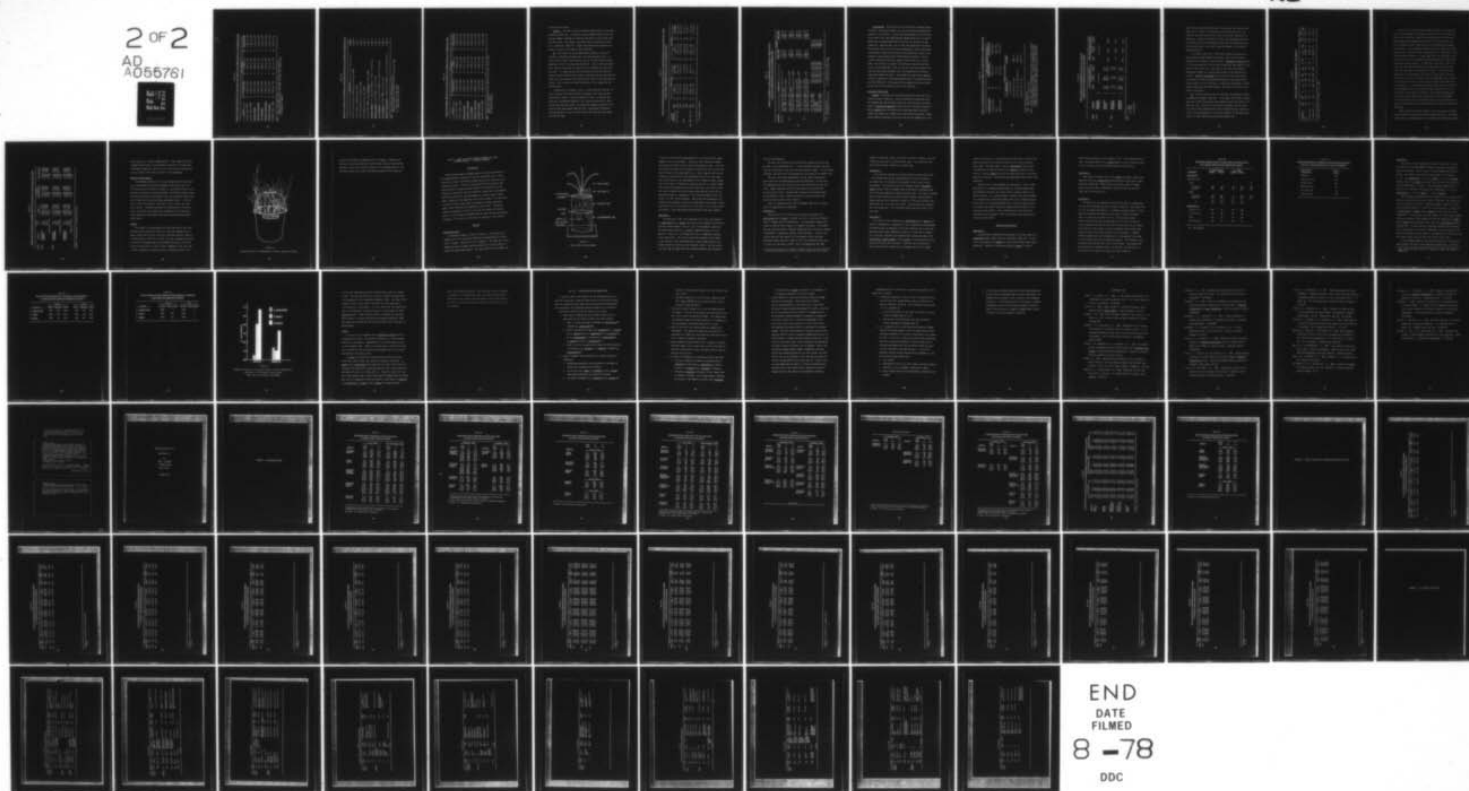
Table 27

Means and Standard Deviation of Bulk Densities (g/cm$^3$) for Dredged Material in Greenhouse Study

| Species | | Bulk Density | | | | |
|---|---|---|---|---|---|---|
| | N | Silt and Clay | N | Sand | N | Sand and Clay |
| Initial (July 1974) | 21 | 0.390 ± 0.050 | 21 | 1.503 ± 0.102 | 21 | 1.494 ± 0.154 |
| Control (March 1976) | 7 | 0.434 ± 0.077 | 8 | 1.507 ± 0.180 | 8 | 1.323 ± 0.168 |
| Spartina patens | 7 | 0.470 ± 0.097 | 9 | 1.389 ± 0.106 | 7 | 1.402 ± 0.127 |
| Borrichia frutescens | 8 | 0.420 ± 0.080 | 9 | 1.407 ± 0.175 | 8 | 1.319 ± 0.197 |
| Iva frutescens | 8 | 0.463 ± 0.070 | 9 | 1.308 ± 0.174 | 9 | 1.418 ± 0.116 |
| Spartina cynosuroides | 7 | 0.448 ± 0.048 | 6 | 1.393 ± 0.238 | 8 | 1.230 ± 0.128 |
| Distichlis spicata | 8 | 0.400 ± 0.040 | 9 | 1.331 ± 0.249 | 9 | 1.316 ± 0.181 |
| Combined (March 1976) | 45 | 0.443 ± 0.070 | 50 | 1.414 ± 0.172 | 49 | 1.335 ± 0.161 |

NOTE: Cores from depths of 0-5, 5-10, and 10-15 cm were combined.
Samples were collected 31 July 1974 (initial) and 2 March 1976.
N = number of samples.

Table 28

Results of t-test for Differences in Mean Bulk Densities for Greenhouse Dredged Material

| Comparison | t-value |
|---|---|
| Initial silt and clay vs combined silt and clay (1976) | 4.308 ** |
| Initial sand vs combined sand (1976) | 2.213 * |
| Initial sand and silt vs combined (1976) | 3.903 * |
| Sand (1976) vs sand and clay (1976) | 3.434 ** |
| Initial sand (1976) vs Iva frutescens on sand (1976) | 2.301 * |
| Spartina patens on silt and clay (1976) vs initial silt and clay | 2.840 ** |
| Spartina patens on sand (1976) vs initial sand | 3.300 ** |
| Iva frutescens on silt and clay (1976) vs initial silt and clay | 3.131 ** |
| Iva frutescens on sand (1976) vs initial sand | 3.844 ** |
| Spartina cynosuroides on sand and clay (1976) vs initial sand and clay | 4.306 ** |

NOTE: Only significant differences are listed.
Samples collected 31 July 1974 (initial) and 2 March 1976.

\* Significant at 0.05 level.
\*\* Significant at 0.01 level.

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Table 29

Means and Standard Deviation of Carbon Values for Dredged Material in Greenhouse Study

| Species | N | Silt and Clay | % Carbon N | Sand | N | Sand and Clay |
|---|---|---|---|---|---|---|
| Initial (July 1974) | 12 | 3.309 ± 0.225 | 9 | 0.048 ± 0.003 | 12 | 0.599 ± 0.179 |
| Control (March 1976) | 12 | 3.037 ± 0.842 | 12 | 0.001 ± 0.002 | 12 | 0.462 ± 0.323 |
| Spartina patens | 12 | 2.819 ± 1.051 | 12 | 0.011 ± 0.016 | 12 | 0.334 ± 0.190 |
| Borrichia frutescens | 12 | 2.893 ± 1.124 | 12 | 0.014 ± 0.029 | 12 | 0.522 ± 0.308 |
| Iva frutescens | 12 | 2.816 ± 0.896 | 12 | 0.098 ± 0.110 | 12 | 0.492 ± 0.267 |
| Spartina cynosuroides | 12 | 2.868 ± 1.032 | 12 | 0.010 ± 0.022 | 12 | 0.712 ± 0.143 |
| Distichlis spicata | 12 | 2.473 ± 0.644 | 12 | 0.046 ± 0.060 | 12 | 0.412 ± 0.343 |
| Combined (March 1976) | 72 | 2.818 ± 0.927 | 72 | 0.030 ± 0.062 | 72 | 0.479 ± 0.289 |

NOTE: Samples were collected 31 July 1974 (initial) and 2 March 1976.
Values in % carbon.
N = number of samples.

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the data are not clear.

Salinity. Soil water salinity differed significantly in the three substrates (Table 30). In addition, water obtained from silt and clay and sand showed a decrease in salinity from 1974 to 1975 in both long and short tubes. The change in the short tube in sand was not, however, significant (Table 31). Water from sand and clay showed an increase in salinity from 1974 to 1975 (Table 30).

pH. The results of the pH determination showed, in only two instances, differences between water from long and short tubes. In 1974, the pH of water from the short tube in silt and clay was 7.60 as compared to 7.44 in the long tube (Table 30). Also in 1974, the pH of water from the short tube in sand was 7.41 as compared to 7.09 in the long tube. In comparing the various substrates, pH of the water obtained from both long and short tubes in sand and clay was significantly lower than that obtained from long and short tubes in the other two substrates. The t-values are highly significant in all comparisons for 1974 and 1975.

In observing the changes in pH in a given substrate from year to year, the pH of soil water from the long tube in silt and clay was significantly higher in 1975 as compared to 1974. In sand and clay there was a significant decrease in soil water pH from 1974 to 1975 in both long and short tubes. No significant changes occurred in soil water pH from sand between 1974 and 1975. Significant differences occurred between silt and clay and sand in both long and short tubes for 1974 and 1975.

Table 30

Means and Standard Deviations of pH and Salinity for Water Recovered from Long and Short Tubes

in Three Types of Dredged Material from the Greenhouse Study

| Dredged Material | Year | Short Tube | | | | Long Tube | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | pH | N | Sal (‰) | N | pH | N | Sal (‰) |
| Silt and clay | 1974 | 42 | 7.60 ± 0.07 | 21 | 32.2 ± 4.6 | 42 | 7.44 ± 0.30 | 63 | 31.4 ± 2.6 |
| | 1975 | 21 | 7.61 ± 0.25 | 15 | 24.5 ± 6.4 | 21 | 7.75 ± 0.35 | 21 | 25.5 ± 4.9 |
| Sand | 1974 | 26 | 7.41 ± 0.27 | 18 | 2.4 ± 0.8 | 42 | 7.09 ± 0.27 | 83 | 3.6 ± 1.1 |
| | 1975 | 21 | 7.36 ± 0.47 | 5 | 2.0 ± 0.7 | 21 | 7.07 ± 0.35 | 16 | 2.5 ± 1.1 |
| Sand and clay | 1974 | 37 | 5.49 ± 1.92 | 22 | 8.6 ± 1.7 | 42 | 5.83 ± 1.86 | 64 | 7.8 ± 3.3 |
| | 1975 | 21 | 4.04 ± 1.06 | 1 | 10.0 - | 21 | 4.47 ± 1.11 | 2 | 12.0 ± 0.0 |

N = Number of samples.

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Table 31

Results of Student's t-test to Determine Differences in Mean Salinity
and pH for Dredged Material from the Greenhouse Study

| Parameter | Comparison | t-value | |
|---|---|---|---|
| | | Short tube | Long tube |
| Salinity | Silt and clay (1974) vs silt and clay (1975) | 4.201 *** | 7.070 *** |
| | Sand (1974) vs sand (1975) | 0.335 N.S. | 3.662 ** |
| | Sand (1974) vs sand and clay (1975) | 14.215 *** | 10.923 *** |
| pH | Silt and clay (1974) vs silt and clay (1975) | 1.301 N.S. | 3.669 ** |
| | Sand (1974) vs sand (1975) | 1.462 N.S. | 1.509 N.S. |
| | Sand and clay (1974) vs sand and clay (1975) | 3.187 ** | 3.079 ** |
| | Silt and clay (1974) vs sand (1974) | 4.336 *** | 5.680 *** |
| | Silt and clay (1974) vs sand and clay (1974) | 7.119 *** | 5.539 *** |
| | Sand (1974) vs sand and clay (1974) | 5.049 *** | 4.346 *** |
| pH | Silt and clay (1975) vs sand (1975) | 2.150 * | 6.327 *** |
| | Silt and clay (1975) vs sand and clay (1975) | 15.049 *** | 12.980 *** |
| | Sand (1975) vs sand and clay (1975) | 13.126 *** | 10.289 *** |
| | Silt and clay (1974) Short tube vs long tube | 3.383 *** | |
| | Silt and clay (1975) Short tube vs long tube | 1.502 N.S. | |
| | Sand (1974) Short tube vs long tube | 4.782 *** | |
| | Sand (1975) Short tube vs long tube | 2.266 N.S. | |
| | Sand and clay (1974) Short tube vs long tube | 0.686 N.S. | |
| | Sand and clay (1975) Short tube vs long tube | 1.289 N.S. | |

N.S.   Not significant.
*   Significant at 0.05 level.
**   Significant at 0.01 level.
***   Significant at 0.001 level.

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Infiltration. The results of the infiltration study were quite variable. As one would expect, the coarse sand had the highest percentage of infiltration. In only one sand container was an infiltration value of less than 100% achieved (79.4%) which led to a mean of 95.6% with a standard deviation of 20.2% for infiltration on sand (Table 32). Sand and clay, and silt and clay showed much variation. The variation of silt and clay can be explained in part by the extensive growth of algae on the surface of the substrate in some of the containers thus preventing the infiltration of rainfall. On containers lacking the algal mat, percent infiltration was as high as 100%. The variation in percent infiltration on sand and clay containers can be explained in part by the fact that the surface of the sand and clay became extremely hard, thus preventing the influx of significant amounts of water. Even though the results were somewhat variable, significant differences between some of the substrates were observed (Table 32). Plant growth did not appear to have any effect on the rate of infiltration on any of the substrates.

## Intertidal Field Study

Biomass. The results of the harvesting of the intertidal field study are shown in Table 33. Since no significant differences were seen between the tubs and lower level pits, only the pits are represented. Borrichia frutescens did not survive at the lower elevation. The D. spicata plants survived on all three substrates, but aerial biomass was greater ($\alpha = 0.08$) on the sand and clay substrate. Underground biomass differences were less clear and the probability of the

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Table 32

Results of Simulated Rainfall on Three Types of Dredged Material in Greenhouse Study

| Dredged material | N | Mean and Standard Deviation | |
|---|---|---|---|
| | | % Water Content | % Infiltration |
| Silt and clay | 20 | 60.0 ± 4.2 | 28.6 ± 36.1 |
| Sand | 21 | 7.5 ± 2.1 | 95.6 ± 20.2 |
| Sand and clay | 21 | 18.0 ± 5.5 | 41.9 ± 31.0 |

Results of t-test*

| Comparison | t-value |
|---|---|
| % Infiltration | |
| Silt and clay vs sand | 7.380 *** |
| Silt and clay vs sand and silt | 1.268 N.S. |
| Sand and silt vs sand | 6.700 *** |

* N.S.  Not significant.
*** Significant at 0.001 level.

NOTE:  Percent water content of dredged material refers to the water content at time of application of rainfall. Infiltration expressed as percentage infiltrated from total amount applied. Time of application, 5 minutes; mean amount of water applied per container, 440 ± 46 ml.

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Table 33

## Aerial Biomass and Underground Biomass for Intertidal

## Dredged Material Revegetation Study, March 1976

| Level | Species | | Aerial Biomass (g/m$^2$)* | | | Underground Biomass (g/m$^2$)* | | |
|---|---|---|---|---|---|---|---|---|
| | | | Sand | Sand and Clay | Silt and Clay | Sand | Sand and Clay | Silt and Clay |
| Lower | Borrichia frutescens | L | no survival | | | no survival | | |
| | | D | | | | | | |
| | | T | | | | | | |
| | Distichlis spicata | L | 77.0 | 168.3 | 10.2 | | | |
| | | D | 18.0 | 40.8 | 24.3 | | | |
| | | T | 95.0 | 209.8 | 34.5 | 819.4 | 1555.6 | 857.6 |
| Upper | Borrichia frutescens | L | 0.0 | 2.6 | 0.0 | | | |
| | | D | 0.0 | 4.3 | 3.8 | | | |
| | | T | 0.0 | 6.9 | 3.8 | 0.0 | 2109.4 | 243.1 |
| | Sporobolus virginicus | L | 48.6 | 172.3 | 3.2 | | | |
| | | D | 18.9 | 91.3 | 17.4 | | | |
| | | T | 67.5 | 263.5 | 20.7 | 684.0 | 2479.2 | 350.7 |

NOTE: L - live
D - dead
T - total.

* dry weight.

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growth being significantly greater on the sand and clay substrate was much less ($\alpha$ = 0.30). The root/shoot ratios were 8.62, 7.42, and 24.85 for the sand, sand and clay, and silt and clay substrates, respectively. Resource allocation to aerial and underground parts was not different for the two dominantly sandy types of dredged material, but more was placed in root and rhizome development on the heavier textured material.

In the upper tidal level, differences between substrates were much clearer, perhaps because at the lower level the tidal water moderated the influence of the substrates. Sporobolus virginicus grew on all three substrates, but the aerial growth was much greater on the sand and clay mixture ($\alpha$ = 0.01) than on the other two sediments. Underground biomass was likewise much greater on the sand and clay mixture. Borrichia frutescens did not survive on the sand and produced about 10 times more underground biomass on the sand and clay mixture than on the silt and clay. In March the differences in underground biomass were much more dramatic than those of the aerial portions of the plants.

pH. The poor growth on the silt and clay was predictable based on expected pH changes (Table 34). In the upper tidal level, the sand had a pH of 6.59, the sand and clay mixture a pH of 5.80, and the silt and clay, 3.55. The pH of 7.30 in buffer indicates a fairly large acid reserve which combined with nearly 3% carbon content usually results in the development of a "cat clay" problem. At the lower tidal level, all three substrates had pH values above 7.00.

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Table 34

Chemical Properties of Dredged Material from Georgia[*]

| Material | $pH^W$ | $pH^B$ | P | K | Ca | Mg | Na | Fe | Mn | Cl | $NO_3$ | Total N | Total C | $NH_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sand | 8.4 | 8.00 | 9 | 25 | 300 | 60 | 140 | 9 | 2 | 56,700 | 3 | 0.08 | 0.00 | 6 |
| Sand and clay | 5.6 | 7.35 | 27 | 25 | 720 | 310 | 360 | 49 | 7 | 17,000 | 18 | 0.08 | 0.40 | 17 |
| Silt and clay | 7.4 | 7.30 | 2 | 1200 | 5580 | 1980 | 11900 | 2 | 33 | 184,300 | 13 | 0.36 | 2.97 | 41 |

[*] Total C and N are in %; others are in ppm.

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In view of the relatively poor growth of plants on the sand and clay in the greenhouse, the success of the plants in the field study was at first surprising. When the substrate profiles in the tubs in the greenhouse were compared with those in the field and with the pits, differences which could account for the differential response were noticed. In the greenhouse tubs the soils were held near filled capacity and no natural rainfall reached the soil. Furthermore, since water was added frequently in small quantities, the substrate did not dry out and thus did not produce conditions conducive to rapid leaching during the next watering. At the field sites high in the intertidal zone the substrate dried due to evapotranspiration and conditions were thus ideal for leaching by rainfall. At the end of the experiment in the greenhouse, the lenses of clay mixed in the sand were intact and nearly the same as when the experiment was initiated. At the field sites, the silt and clay was leached to the lower part of the profile. In the greenhouse material there had been relatively little degradation of the particulate organic material, but at the field site it was almost all oxidized. The problems regarding the cat clay situation which would be affected by vertical placement in the intertidal zone were considered, but not the soil-forming processes of eluviation and illuviation working so rapidly to modify the substrates.

Table 35 shows the percent carbon in the three types of dredged material under the various plant and elevation conditions. The variations within one dredged material were greater than differences between

Table 35

Carbon Value (% Carbon) of Dredged Material from Plots in Field Study, March 1976

| Level | Species | Depth cm | Sand | % Carbon* Sand and Clay | Silt and Clay |
|---|---|---|---|---|---|
| Lower | Distichlis spicata | 0-5 | 0.082 (.085) | 0.141 (.054) | 2.290 (.355) |
| | | 5-10 | 0.290 (.295) | 0.166 (.363) | 2.100 (.338) |
| | | 10-15 | 0.026 (.036) | 0.007 (.016) | 2.223 (.502) |
| | | 15-35 | 0.035 (.069) | 0.016 (.019) | 2.224 (.345) |
| | Integrated value | | 0.077 | 0.054 | 2.216 |
| Upper | Borrichia frutescens | 0-5 | 0.182 (.201) | 0.186 (.166) | 2.121 (.600) |
| | | 5-10 | 0.115 (.150) | 0.016 (.013) | 2.465 (.532) |
| | | 10-15 | 0.005 (.007) | 0.043 (.050) | 2.340 (.441) |
| | | 15-35 | 0.009 (.022) | 0.038 (.052) | 2.281 (.571) |
| | Integrated value | | 0.048 | 0.057 | 2.293 |
| | Sporobolus virginicus | 0-5 | 0.096 (.073) | 0.128 (.006) | 1.992 (.957) |
| | | 5-10 | 0.093 (.135) | 0.067 (.064) | 2.311 (.627) |
| | | 10-15 | 0.018 (.012) | 0.504 (.653) | 2.764 (.684) |
| | | 15-35 | 0.063 (.099) | 0.182 (.232) | 2.686 (.524) |
| | Integrated value | | 0.066 | 0.204 | 2.544 |

* Numbers in parentheses are standard deviation.

plant species on a single dredged material. When compared with the dredged material kept in the greenhouse, there were no significant differences between the sand or the silt and clay, but the sand and clay was lower in the field study than in the greenhouse.

## Need for Field Bioassay

The apparent necessity to test each dredged material under each set of environmental conditions prompted the design and test of a field bioassay unit depicted in Figure 13. Holes were drilled in the bottom of the bucket to provide drainage. The 0.83-cm hardware cloth top altered the aerial environment little, but prevented raccoons and other large animals from destroying experimental plots. A slot was cut to allow free access of tidal water, snails, crabs, and other small animals. Following the period of implantation in the natural marsh, the buckets were removed and transported to the laboratory where appropriate measurements were made on above-and below-ground plant growth.

## Summary

The studies in the greenhouse and field show that at this time predicting which plants will grow on a particular dredged material under a given water salinity and given intertidal elevation requires a local bioassay. With this in mind, a unit was designed which could be filled with dredged material and planted with sprigs at the lab, carried to the field in a truck or boat, implanted at the site, and similarly removed for evaluation after an incubation period. This

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Figure 13

Bucket Modified for Dredged Material-Plant Interaction Studies

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type of assay should be conducted prior to dredging. Based on the results of the assay, decisions could be made relative to the optimum elevation in the tidal zone for disposal of the dredged material, and the plant species which would show optimal growth at that elevation.

## PART VI: MARSH PLANT ROOT GROWTH IN NATURAL SOIL AND DREDGED MATERIAL: A BIOASSAY APPROACH

## Introduction

Establishing marshes on dredged material has positive effects on the dredged material disposal site and the surrounding area. Aerial production of plants contributes through the detritus food web to the surrounding estuary. The root system stabilizes the substrate thus reducing erosion, produces carbon sources for microbial flora, and through the interaction with the substrate, creates soil environmental conditions suitable for the development of a typical natural marsh fauna. Because of the importance of the root systems, it is desirable to predict to what extent they will develop in various substrates under various conditions of temperature and salinity. A bioassay chamber was designed in which to test the root growth of different plants in various types of dredged material under various environmental conditions. The results of the tests are reported in this section.

## Methods

### Experimental Unit

The bioassay chamber is shown in Figure 14. The natural soil chambers were 13 cm long while those for the experimental soil were 10 cm in length. Both were 7.5 cm in diameter. The upper part of the chamber was used to remove cores of natural soil with the plants in place from established marshes. The lower portion of the chamber was

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TEST PLANT

SOIL WELLS

PLEXIGLASS
CHAMBER

NATURAL SOIL

SILICONE

SEAL

EXPERIMENTAL SOIL

ROOTS AT
SOIL-PLASTIC
INTERFACE
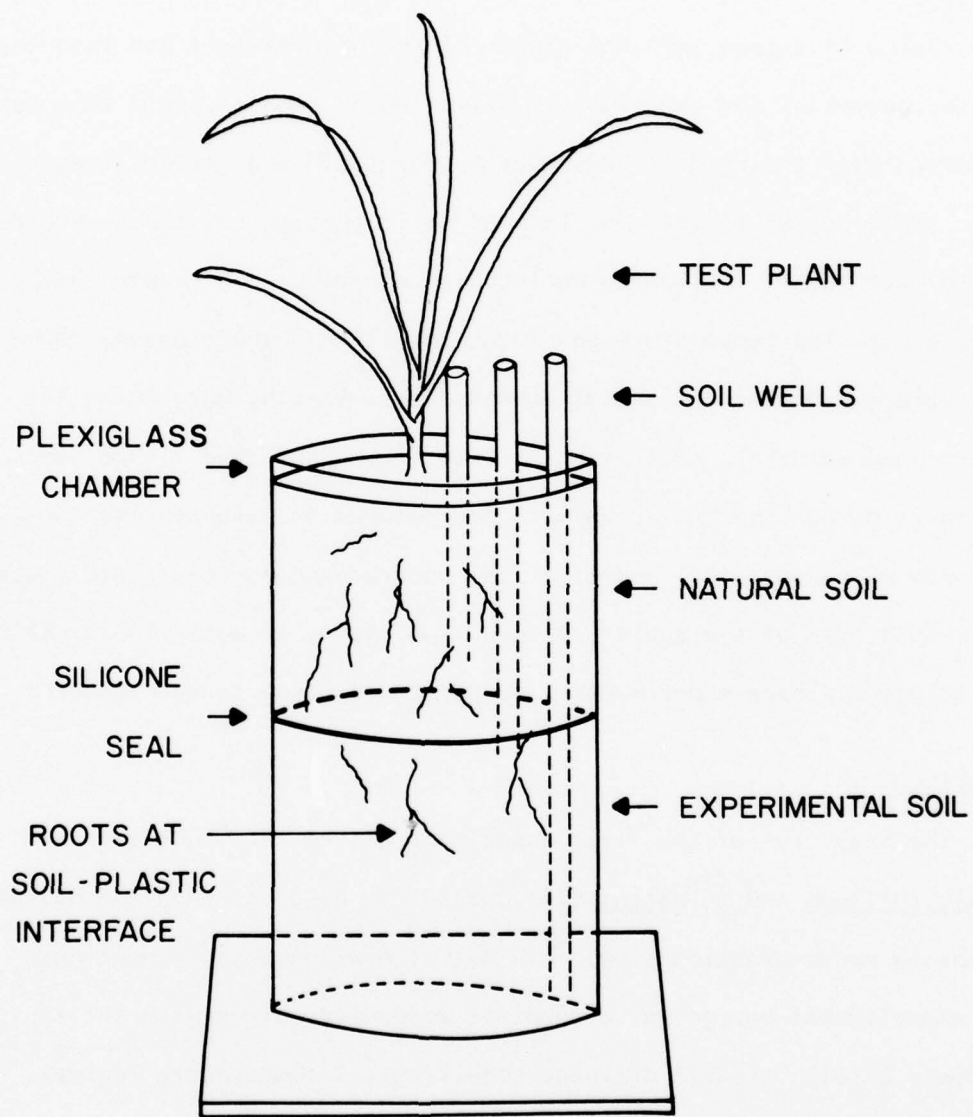
Figure 14

Root Growth Bioassay Chamber

filled with the root-free experimental soil, and the two were sealed together with silicone cement. The entire clear plexiglass chamber was covered with black cloth to retard the growth of algae. Soil wells were placed to extend into the center of the natural soil and into the top and bottom of the experimental soil. Water samples could thus be withdrawn from the natural and experimental soils and various treatments administered to the experimental soils through the tubes extending to that layer. Following an incubation period in a growth chamber under controlled temperature and light conditions, the bioassay chambers were dismantled and aerial biomass determined by harvesting the aboveground material, separating it into living and dead tissue, and drying it at $60^\circ$C before weighing. The natural and experimental soil chambers were separated, and after the underground macro-organic matter was washed free of the substrate on a 1-mm sieve, it was dried at $60^\circ$C and weighed. Three experiments were performed using these chambers.

## Experiment 1

The objective of the first experiment was to test root growth of S. alterniflora and S. patens (two species to be planted on the Bolivar Peninsula marsh-creation site) to a set of environmental conditions. The experimental design was a complete randomized block with the 2 species, 2 salinities, 2 drainage conditions, 2 temperature regimes, and 4 replications. The natural cores were collected from a Sapelo Island, Georgia, marsh and placed over a sandy dredged material collected from Bolivar Peninsula near Galveston, Texas. The two salinities were 10‰ and 20‰ while the drainage conditions were saturated

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soil and field capacity.

The above soil condition was maintained by changing the water once per week in the experimental soil. In the saturated treatment the water level was maintained at the top of the experimental chamber. In the drained treatment, the water level was maintained at the bottom of the deepest well.

The winter and summer temperatures and day length regimes were means taken from the meteorological data for Galveston. In the winter the temperature was 16°C during the 12-hr day and 9°C during the 12-hr night. Summer conditions were 32°C during the 14-hr day and 26°C during the 10-hr night. Maximum light intensity in the growth chamber was 5000 fc,* half of which was turned on during the hour after sunrise and off an hour prior to sunset.

After an incubation period from 14 November 1975 until 15 January 1976, the experiment was terminated.

Experiment 2

The objective of this study was to compare root growth of S. alterniflora and S. patens in natural soil and in three very different types of dredged material from Georgia. Two temperature regimes were tested to observe plant responses to seasonal variations. This experiment was designed around a complete randomized block using the 2 species, 4 substrates, 2 temperature regimes, and 8 replicates. The four substrates used were the natural soil from Sapelo Island, sand from Buttermilk Sound, sand with lenses of clay from the Darien River, and silt and clay from Jekyll Island. Since the temperature and light

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* Multiply footcandles by 10.76391 to obtain lumens per square meter.

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regimes in Galveston, Texas, are similar to those in Georgia, the same conditions were used as in the previous study. This assay was incubated from 30 January 1976 until 31 March 1976.

## Experiment 3

This study was designed to simulate conditions which would occur if the dredged material was deposited above the tidal influence or was deposited in a freshwater area adjacent to the natural saline environment. The study was done with freshwater plants (Eleocharis obtusa) using 5 types of dredged material and natural freshwater pond mud at the warm temperature regime previously used. The types of dredged material were Galveston area sand (saline); Georgia sand (brackish); Georgia sand and clay (brackish); Georgia silt and clay (saline); and a James River, Va., silt and clay (fresh). The substrates were watered only with fresh water. The incubation period was from 14 April to 15 June 1976.

## Experiment 4

As a result of the response of S. alterniflora and S. patens root growth to temperature in experiments 1 and 2, experiment 4 was designed. The objective was to determine if the root growth was due to root temperatures alone, shoot temperatures alone, or a whole plant response. This study was conducted using chambers which allowed the roots of S. alterniflora, Spartina bakeri, and S. patens to be maintained at a temperature different than the shoots. Each test unit consisted of a core of natural plant stand 6.8 cm in diameter and 15 cm in length

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placed in the center of a square plastic tub 20 cm on a side with the space around the core filled with root-free soil from the natural plant stand. The water table in the S. alterniflora tubs was kept 5 cm below the surface while that for S. patens was held at 10 cm. The soil in the S. bakeri test units was kept moist but no free water table was maintained. These conditions approximated the natural field conditions.

Eight test units were prepared for each species. Four of each were placed in a randomized block design in a growth chamber where environmental conditions were those used to simulate summer in the earlier studies. In a second chamber, identical tubs and environmental conditions were established except that the soil temperature was held at $19^{\circ}C$ by a refrigerated water bath. After the growth period of 12 weeks the original cores were removed from the center of the tubs and the new growth in the surrounding soil, both aerial and underground, was harvested. Roots and rhizomes were separated and all parts dried at $60^{\circ}C$.

## Results and Discussion

### Experiment 1

No significant differences were observed in the root growth of S. alterniflora under summer and winter conditions (Table 36). In contrast, root growth of S. patens was significantly higher under winter conditions. These data indicate that when S. patens is used for

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marsh-creation projects in the southeast, fall is the optimum planting time. The growth pattern of S. patens appears to favor resource allocation to the roots and thus increases substrate stabilization.

## Experiment 2

Root growth in natural soils of S. patens was greater under winter conditions while S. alterniflora exhibited greater growth under summer conditions (Table 36). Plant growth on the three types of dredged material did not differ significantly from each other but was much lower than in the natural soil.

## Experiment 3

The results of the experiment with the five types of dredged material and the freshwater pond mud are shown in Table 37. Root growth fell into the following three groups: 1) greatest on Georgia sand; 2) intermediate on pond mud and James River mud; and 3) least on Galveston sand, silt and clay, and sand and silt. The relatively greater growth on Georgia sand can be explained by the initial low salinity of the substrate (1‰) and the fact that the salts were easily leached. The relatively lower growth in the two freshwater muds may have been caused by high sulfide concentrations in the substrates. Although sulfide concentrations were not measured, it was apparent by the odor of the substrate that free sulfides were present. The sulfides in the freshwater muds may have been toxic to root growth. The reduced root growth obtained in Galveston sand, silt and clay, and sand and silt was caused by the higher salt content of these substrates.

## Table 36

### Underground Biomass (mg) of Plants Grown in Bioassay Units
### with Several Substrate and Temperature Regimes

| Treatment | S. alterniflora | | S. patens | | |
| --- | --- | --- | --- | --- | --- |
| | Summer | Winter | Summer | Winter | |
| Experiment 1 | | | | | |
| Galveston sand | | | | | |
| 10 ‰ | | | | | $\overline{X}$ |
| saturated | 130 | 99 | 28 | 164 | 139 |
| drained | 148 | 106 | 73 | 248 | 144 |
| 20 ‰ | | | | | |
| saturated | 158 | 146 | 7 | 238 | 137 |
| drained | 67 | 164 | 30 | 272 | 133 |
| $\overline{X}$ | 126 | 129 | 34 | 230 | |
| Experiment 2 | | | | | |
| natural soil | 630 | 50 | 100 | 620 | |
| silt and clay | 80 | NT | NT | 80 | |
| sand | 80 | NT | NT | 90 | |
| sand and clay | 50 | NT | NT | 70 | |

NT - not tested.

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Table 37

Underground Biomass of Eleocharis obtusa Grown in Bioassay
Units with Various Substrates in the Test Chambers

| Experimental Substrate | Biomass (mg) |
|---|---|
| Pond mud | 144 |
| James River mud | 138 |
| Georgia sand | 392 |
| Galveston sand | 57 |
| Silt and clay | 60 |
| Sand and clay | 78 |

Experiment 4

The results of this experiment are shown in Table 38. The two-way analysis of variance (ANOVA) revealed a significant temperature species interaction. Hence a series of one-way ANOVA tests were performed. Root growth in the warm soil was greater in all species ($\alpha$ = 0.1, S. alterniflora; $\alpha$ = 0.02, S. bakeri; $\alpha$ = 0.05, S. patens). Rhizome growth in S. bakeri was greater than the other two species at the warm temperature ($\alpha$ = 0.07). Total underground production was higher for all species at the higher soil temperature ($\alpha$ = 0.10, S. alterniflora; $\alpha$ = 0.01, S. bakeri; $\alpha$ = 0.05, S patens).

Aerial biomass associated with the original core and initially root-free soil outside the core area is shown in Table 39. The response of the three species was similar. The warm treatment resulted in significantly greater biomass ($\alpha$ = 0.01) for all three species. The $Q_{10}$* for S. alterniflora, S. bakeri, and S. patens was 2.00, 1.90, and 2.54, respectively. In the case of the root systems, all three species showed a positive response to warm temperature with the response of S. bakeri and S. patens being much greater than that of S. alterniflora (Figure 15 and Table 38). The data from this experiment indicate the differences in root growth seen in the earlier experiments were the results of the effect of temperature on the shoots or the combination of shoots and the root system rather than just the direct effect on the roots.

A two-way ANOVA showed no significant interaction, thus the three species behaved the same to the temperature differential. The effect

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\* $Q_{10}$ = factor by which respiration changes for every 10°C change in temperature.

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Table 38

Root and Rhizome Growth (mg dry weight) of Three Species

of Spartina Grown Under Two Temperature Regimes

| Species | Warm | | | Cool | | |
|---|---|---|---|---|---|---|
| | Roots | Rhizomes | Total | Roots | Rhizomes | Total |
| S. alterniflora | 1430 | 400 | 1830 | 890 | 140 | 1030 |
| S. bakeri | 9880 | 1480 | 11350 | 4250 | 620 | 4870 |
| S. patens | 2480 | 110 | 2590 | 990 | 200 | 1190 |

Table 39

Aerial Biomass (mg dry weight) of Three Species of Spartina

Grown Under Two Temperature Regimes

| Species | Warm | | Cool | |
|---------|---------|-------------|---------|-------------|
| | In core | Out of core | In core | Out of core |
| S. alterniflora | 6950 | 0 | 3910 | 0 |
| S. bakeri | 17180 | 1510 | 10040 | 0 |
| S. patens | 9440 | 130 | 4340 | 0 |
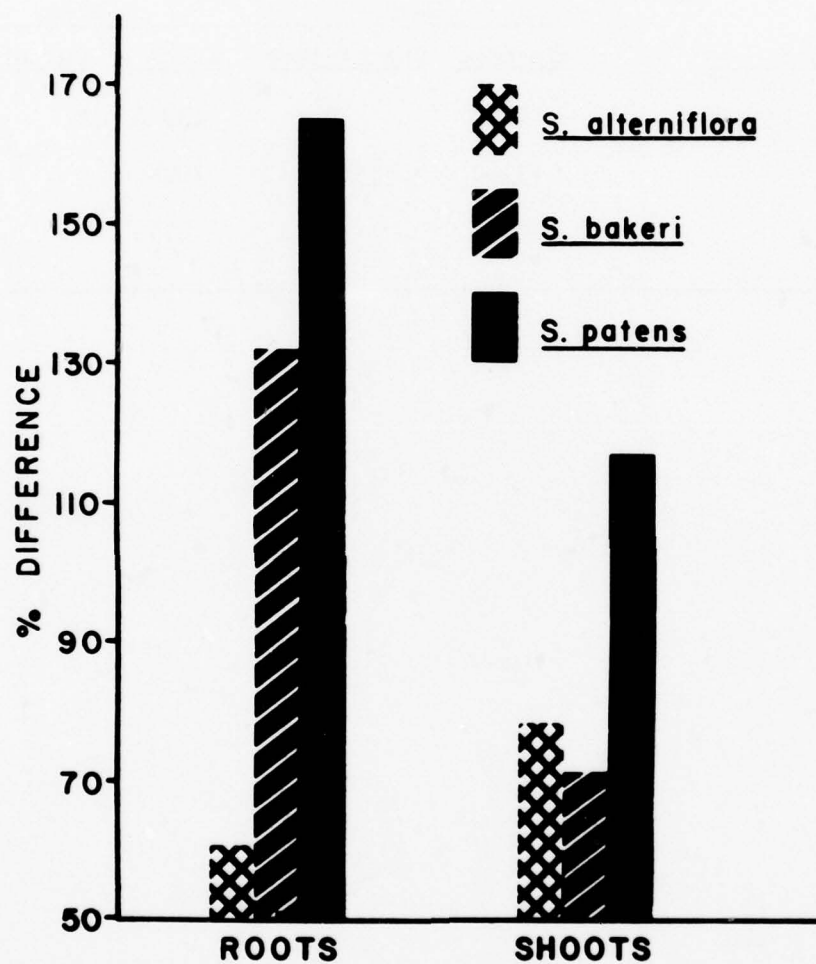
Figure 15

Response of Roots out of Core and Shoots in Core to Temperature
Expressed as % Difference in Total Biomass
When Grown in the Warmer Environment

of cool root temperatures may have reduced shoot growth in a number of ways. Net $CO_2$ assimilation by a variety of plants has been shown to be regulated by root temperature (Brouwer, 1963). The shape of the response curves in many studies indicates the root temperature is limiting only at the extremes. It is not likely that the temperatures used in the experiment (19 and 27°C) were at the extremes for these Spartina species. Other possible effects of temperature could have been on water or nutrient absorption and movement (Takeshima, 1964). The temperature differential may also have affected the allocation of photosynthate.

## Summary

In a test with a freshwater plant (Eleocharis obtusa) and five dredged material types, root growth was greatest in a sandy dredged material of low salinity. Approximately 1/3 as much growth occurred in two freshwater muds. Growth in a saline sand, a saline silty clay, and a brackish mixture of sand and clay produced only 1/7 the growth obtained with low salinity sand.

S. patens root growth was increased when the whole plant was grown under cooler rather than warmer environmental conditions. S. patens and S. alterniflora root growth did not differ under drained or saturated conditions when a sand substrate was used. Equal growth was obtained with either 10 or 20‰ salinity. Growth in natural soil was 6-12 times greater than in the various types of dredged material tested. When the soil temperature alone was reduced, three species of Spartina (S. alterniflora, S. bakeri, and S. patens) all showed reduced

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aerial and underground growth.  This indicates that the increased

root growth at low temperatures seen in two earlier experiments

where whole plants were studied was either a whole plant effect or

an effect on the shoots alone, not simply a direct effect on the

root systems.

PART VII:   CONCLUSIONS AND RECOMMENDATIONS

A study was made of the dynamics of the underground portion of some salt marsh plants along the western coast of the Atlantic Ocean. The soils supporting those plants were characterized and experiments were conducted on the substrate selective properties of the plants.

Conclusions resulting from the study are as follows:

1. Three types of underground macro-organic matter profiles were found for the series of plants and sites studied.

    a. Type 1, uniform with depth (Creekbank <u>S</u>. <u>alterniflora</u>-GA; Creekbank <u>S</u>. <u>alterniflora</u>-ME).

    b. Type 2, decreases with depth (<u>B</u>. <u>frutescens</u>-GA; <u>D</u>. <u>spicata</u>-GA; <u>J</u>. <u>gerardi</u>-DL,ME; <u>J</u>. <u>roemerianus</u>-GA; <u>S</u>. <u>virginica</u>-GA, DL; <u>S</u>. <u>cynosuroides</u>-GA; High marsh <u>S</u>. <u>alterniflora</u>-GA; <u>S</u>. <u>patens</u>-GA,DL,ME; <u>S</u>. <u>virginicus</u>-GA).

    c. Type 3, at first increasing with depth and then decreasing as with Type 2 (<u>D</u>. <u>spicata</u>-DL; <u>P</u>. <u>communis</u>; Creekbank <u>S</u>. <u>alterniflora</u>-ME).

2. Annual increments were calculated as a minimum estimate of production.

    a. Underground production usually equalled or exceeded reported aerial productivity estimates.

    b. In the case of <u>S</u>. <u>patens</u>, <u>S</u>. <u>virginica</u>, and <u>D</u>. <u>spicata</u>, underground production increased with latitude.

    c. The annual increment for <u>S</u>. <u>virginica</u> and <u>D</u>. <u>spicata</u> was

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greater in Delaware than Georgia, but the turnover times were similar.

   d.  The mean production for the 18 stands sampled was 654 $g/m^2$ (range 1686-80) while the mean turnover time was 57 months (range 224-18.4).

3. The macro nutrient content (N, P, K) of the MOM decreased with depth. Since no similar pattern was observed with carbon, the C:N ratio decreased with depth. This deeper material probably decays very slowly because of its composition and the anaerobic environment under which it grows.

4. Most of the marsh soils studied could be categorized as Sulfaquests. The chemical and physical characteristics described will extend the small data base available on marsh soils in Georgia, Delaware, and Maine.

5. Water movement through 13 marsh soils in Georgia, Delaware, and Maine appears to be rather slow in view of the long retention of extractable rhodamine WT when a pulse of dye was injected into the soil.

6. A variety of responses to a nitrogen pulse were observed.

   a.  A positive response in biomass was obtained with S. virginica and high marsh S. alterniflora in Georgia, as well as J. gerardi and S. virginica in Delaware.

   b.  Although S. virginicus in Georgia did not respond with an increase in biomass, the nitrogen content increased. An increase in chlorophyll was noted in B. frutescens

in Georgia and <u>D</u>. <u>spicata</u> in Delaware.  No responses to nitrogen were detected in the Maine samples.

7. Several methods of assessing marsh plant growth on dredged material were evaluated.  They varied from a method used in growth chambers to one used on-site in the field. The growth chamber method proved especially useful in testing one or two variables on root growth in a dredged material. An intermediate method designed for greenhouse use appeared to be least useful since it had the disadvantage of the artificial nature of the studies out of the field without the completely controlled conditions achieved in the growth chamber.  The most useful method for examining the practical problems faced in trying to vegetate dredged material was the field bioassay.  Although the environmental conditions in the field are not always known, they do represent the combination of factors to which the plants will be exposed.  Some of the differences between growth chamber, greenhouse, and field studies were predicted based on soil tests and pH, but other factors such as the leaching of clay from the top layers by rainfall and percolating tidal water were not.  Results such as these emphasized the need for a bioassay technique which could be used to test specific plant responses to specific dredged material under specific environmental conditions.

Recommendations as to the use of the material contained in this report are as follows:

1. Information contained in Parts II and III characterizes the natural marsh root system dynamics and soil conditions in Georgia, Delaware, and Maine. This information can be used to aid in determining:

   a. which marsh plants will be likely to do well on various kinds of dredged material, and

   b. when natural marsh conditions have been achieved in marshes developed on dredged material.

2. It is suggested that, as more data are collected on dredged material considered potential soil for growing marsh plants, the general methods of soil analysis described in this report be used. In this way a large set of data can be accumulated which will allow marsh ecologists to do the same kinds of correlations between soil tests and plant growth that agricultural researchers have done for years. In the soils examined, the most useful combinations of parameters in predicting marsh plant success were:

   a. soil texture,

   b. pH properties (pH in situ, pH in water, and pH in buffer),

   c. salinity (in situ, leachable, desalination index),

   d. total nitrogen (which can be obtained by correlation with carbon).

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3. In the future, accurate prediction of plant performance may
   be made based on knowledge about all plant requirements and
   dredged material behavior under a variety of environmental
   conditions. A field bioassay prior to dredging is strongly
   recommended to aid in predicting the outcome of planting
   specific marsh plants on a specific dredged material under
   a specific set of environmental conditions.

## LITERATURE CITED

Adams, F., and Evans, C. E. 1962. A rapid method for measuring lime
requirement of red-yellow podzolic soils. Soil Science Society of
America, Proceedings. 26:355-357.

Arnon, D. A. 1949. Copper enzymes in isolated chloroplasts; poly-
phenoloxidase in *Beta vulgaris*. Plant Physiology. 24:1-15.

Bremner, J. M. 1965. "Total nitrogen," Methods of soil analysis. C. A.
Black, ed. Soil Science Society of America, Madison, Wisconsin.
pp 1149-1178.

Bremner, J. M., and Keeney, D. R. 1966. Determination and isotope-
ratio analysis of different forms of nitrogen in soils: 3. ex-
changeable ammonium nitrate, and nitrite by extraction-distilla-
tion methods. Soil Science Society of America, Proceedings.
20(5):577-582.

Broome, S. W., Woodhouse, W. W., and Seneca, E. P. 1973. An investi-
gation of propagation and the mineral nutrition of *Spartina alter-
niflora*, Sea Grant Publication UNC-SG73-14. University of North
Carolina, Chapel Hill, North Carolina.

Brouwer, R. 1963. Some physiological aspects of the influence of
growth factors in the root medium on growth and dry matter pro-
duction. Jaarb. Inst. biol. scheik. Onderz. LandGewass. pp 11-30.

Coultas, C. L., and Calhoun, F. G. 1976. Properties of some tidal
marsh soils in Florida. Soil Science Society of America, Pro-
ceedings. 19:72-76.

128

Gallagher, J. L. 1974. Sampling macro-organic matter profiles in
    salt marsh plant root zones. Soil Science Society of America,
    Proceedings. 38:154-155.

Gallagher, J. L. 1975. Effect of an ammonium nitrate pulse on the
    growth and elemental composition of natural stands of Spartina
    alterniflora and Juncus roemerianus. American Journal of Botany.
    62:644-648.

Gallagher, J. L., and Daiber, F. C. 1974. Primary production of
    edaphic algal communities in a Delaware salt marsh. Limnology
    and Oceanography. 19:390-395.

Gallagher, J. L., Plumley, F. G., and Perkins, H. A. In press.
    Measuring carbon in salt marsh soils. Bulletin of Georgia
    Academy of Science.

Haines, B. L., and Dunn, E. L. 1976. Growth and resource allocation
    responses of Spartina alterniflora Loisel. to three levels of
    $NH_4$-N, Fe, and NaCl in solution culture. Botanical Gazette.
    137:224-230.

Hull, R. J., Lytle, R. W., and Sullivan, D. M. 1972. Seasonal energy
    relations in natural stands of salt water cordgrass (Spartina
    alterniflora Loisel.) 64th Annual Meeting, American Society of
    Agronomy, Miami Beach, Florida.

Isaac, R. A., and Jones, J. B. 1970. Autoanalyzer systems for the
    analysis of soil and plant tissue extracts. Technicon Inter-
    national Congress, Tarrytown, New York. pp 57-64.

129

Isaac, R. A., and Kerber, J. D. 1971. "Atomic Absorption and Flame
Photometry: Technique and Uses in Soil, Plant, and Water Analysis,"
Instrumental methods of analysis of soils and plant tissue. L. M.
Walsh, ed. Soil Science Society of America, Madison, Wisconsin.
pp 17-37.

Jones, J. B., and Warner, M. H. 1969. "Analysis of Plant-Ash Solu-
tions by Spark-Emission Spectroscopy," Developments in applied
spectroscopy. Vol 7A. Plenum Press, New York. pp 150-160.

Lacroix, R. L., Keeney, D. R., and Walsh, L. M. 1970. Potentiometric
titration of chloride in plant tissue extracts using the chloride
in electrode. Soil Science Plant Analysis. 1(1):1-6.

Nelson, W. L., Mehlich, A., and Winters, E. 1953. "The Development,
Evaluation, and Use of Soil Tests for Phosphorus Availability,"
Soil and fertilizer phosphorus. W. H. Pierre and A. G. Norman,
eds. Vol 2, agronomy. Academic Press, New York.

Odum, E. P., and Riedeburg, C. H. 1976. A dye study of interstitial
water flow in tidal marsh sediments. American Society of Limnol-
ogy and Oceanography, 39th Annual Meeting. Savannah, Georgia.

Sokal, R. R., and Rohlf, F. J. 1969. Biometry. W. H. Freeman and Co.,
San Francisco, California.

Strickland, J. D. H., and Parsons, T. R. 1968. A practical handbook
of seawater analysis, No. 167. Bulletin of Fisheries Research
Board of Canada. 311 p.

Sullivan, M. J., and Daiber, F. C. 1974. Response in production of cord grass, _Spartina alterniflora_, to inorganic nitrogen and phosphorus fertilizer. Chesapeake Science. 15:121-123.

Takeshima, H. 1964. Studies on the effects of soil temperature on rice plant growth: 3. effects of root temperature upon water and nutrient absorption at different stages and in alternating temperatures. Crop Science Society of Japan, Proceedings. 32:319-324.

Valiela, I., and Teal, J. M. 1974. Nutrient Limitation in Salt Marsh Vegetation," Ecology of halophytes. R. J. Reimold and W. H. Queen, eds. Academic Press, New York. pp 547-563.

Valiela, I., Teal, J. M., and Persson, N. Y. 1976. Production and dynamics of _experimentally_ enriched salt marsh vegetation: below-ground biomass. Limnology and Oceanography. 19:152-153.

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Appendixes A-C

By

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December 1977

APPENDIX A:  UNDERGROUND BIOMASS

## Table A1a

### Underground Biomass Expressed in $g/m^2$ for Depth Zones in Stands of Marsh Plants in Delaware

| Species | June, 1974 | | | July and August, 1974 | | |
|---|---|---|---|---|---|---|
| | Depth (cm) | $\bar{X}$ | CV | Depth (cm) | $\bar{X}$ | CV |
| Distichlis spicata | 0-5 | 1825 | 27.4 | 0-5 | 2490 | 14.8 |
| | 5-10 | 2712 | 16.4 | 5-10 | 2880 | 6.5 |
| | 10-15 | 2278 | 21.8 | 10-15 | 2527 | 54.5 |
| | 15-20 | 1023 | 11.9 | 15-20 | 946 | 61.3 |
| | 20-35 | 1014 | 51.2 | 20-35 | 1164 | 40.7 |
| Juncus gerardi | 0-5 | 3498 | 55.6 | 0-5 | 2784 | 11.0 |
| | 5-10 | 801 | 36.3 | 5-10 | 1177 | 18.0 |
| | 10-15 | 466 | 19.0 | 10-15 | 869 | 53.2 |
| | 15-35 | 2278 | 68.1 | 15-35 | 1404 | 38.8 |
| | 35-55 | 1648 | 79.2 | 35-55 | 222 | 30.1 |
| Phragmites communis *(between) | 0-5 | 691 | 81.2 | 0-5 | 174 | 58.6 |
| | 5-10 | 1053 | 16.7 | 5-10 | 369 | 57.0 |
| | 10-15 | 1313 | 80.5 | 10-15 | 1064 | 23.7 |
| | 15-20 | 1438 | 137.0 | 15-20 | 521 | 60.9 |
| | 20-35 | 1845 | 89.4 | 20-35 | 899 | 27.6 |
| | 35-55 | 1483 | 1.1 | 35-55 | 346 | 36.0 |
| | 55-75 | 1324 | 105.2 | 55-75 | 181 | 57.2 |
| Phragmites communis *(over) | 0-5 | 838 | 38.6 | 0-5 | 958 | 72.7 |
| | 5-10 | 844 | 52.9 | 5-10 | 928 | 52.2 |
| | 10-15 | 792 | 80.5 | 10-15 | 1404 | 77.5 |
| | 15-20 | 867 | 50.6 | 15-20 | 1048 | 78.2 |
| | 20-35 | 1223 | 30.6 | 20-35 | 1320 | 69.3 |
| | 35-55 | 867 | 33.0 | 35-55 | 573 | 55.4 |
| | 55-75 | 1358 | 130.0 | 55-75 | 278 | 24.9 |
| Salicornia virginica | 0-5 | 1571 | 14.6 | 0-5 | 1653 | 17.6 |
| | 5-10 | 724 | 58.8 | 5-10 | 403 | 32.6 |
| | 10-15 | 367 | 22.4 | 10-15 | 168 | 42.2 |
| | 15-35 | 380 | 31.3 | 15-35 | 231 | 32.1 |

*Over-plant cores were taken with a stem centered in the core and between-plant cores without stems in the core.

$\bar{X}$ = Mean;  CV = Coefficient of Variation.

## Table Alb

### Underground Biomass Expressed in $g/m^2$ for Depth Zones in Stands of Marsh Plants in Delaware

| | | September, 1974 | | | | November, 1974 | |
| Species | Depth (cm) | $\bar{X}$ | CV | Species | Depth (cm) | $\bar{X}$ | CV |
|---|---|---|---|---|---|---|---|
| Phragmites communis *(between) | 0-5 | 475 | 22.6 | Distichlis spicata ** | 0-5 | 1750 | 29.2 |
| | 5-10 | 469 | 50.3 | | 5-10 | 2520 | 34.0 |
| | 10-15 | 928 | 80.3 | | 10-15 | 890 | 41.4 |
| | 15-20 | 935 | 61.8 | | 15-20 | 537 | 41.0 |
| | 20-35 | 1886 | 16.2 | | 20-35 | 528 | 31.6 |
| | 35-55 | 876 | 70.9 | | | | |
| | 55-75 | 559 | 117.5 | | | | |
| Phragmites communis *(over) | 0-5 | 709 | 27.2 | Juncus gerardi ** | 0-5 | 2429 | 12.4 |
| | 5-10 | 980 | 7.1 | | 5-10 | 928 | 17.1 |
| | 10-15 | 1601 | 5.4 | | 10-15 | 686 | 16.6 |
| | 15-20 | 912 | 44.7 | | 15-35 | 1472 | 9.6 |
| | 20-35 | 2053 | 7.3 | | 35-55 | 537 | 16.0 |
| | 35-55 | 1388 | 109.9 | | | | |
| | 55-75 | 980 | 109.4 | | | | |
| Salicornia virginica | 0-5 | 1834 | 9.2 | | 0-5 | 1616 | 8.8 |
| | 5-10 | 598 | 36.9 | | 5-10 | 539 | 34.0 |
| | 10-15 | 308 | 36.6 | | 10-15 | 321 | 13.5 |
| | 15-35 | 358 | 36.7 | | 15-35 | 272 | 42.9 |
| Spartina patens | 0-5 | 2028 | 13.2 | | 0-5 | 2327 | 15.6 |
| | 5-10 | 715 | 34.7 | | 5-10 | 1277 | 42.5 |
| | 10-15 | 340 | 41.1 | | 10-15 | 285 | 44.4 |
| | 15-35 | 457 | 45.1 | | 15-35 | 353 | 31.6 |

*Over-plant cores were taken with a stem centered in the core and between-plant cores without stems in the core.

**Cores taken from other than original stand for comparative purposes.

$\bar{X}$ = Mean;  CV = Coefficient of Variation.

Table Alc

Underground Biomass Expressed in g/m$^2$ for Depth Zones
in Stands of Marsh Plants in Delaware

| Species | Depth (cm) | $\bar{X}$ | CV |
|---|---|---|---|
| | January, 1975 | | |
| Juncus gerardi | 0-5 | 2554 | 27.0 |
| | 5-10 | 661 | 35.1 |
| | 10-15 | 412 | 29.9 |
| | 15-35 | 833 | 61.2 |
| | 35-55 | 326 | 25.4 |
| Salicornia virginica | 0-5 | 1739 | 10.1 |
| | 5-10 | 484 | 17.1 |
| | 10-15 | 226 | 15.8 |
| | 15-35 | 326 | 31.2 |
| Spartina patens | 0-5 | 2087 | 45.0 |
| | 5-10 | 675 | 40.4 |
| | 10-15 | 217 | 39.4 |
| | 15-35 | 217 | 24.0 |
| | March, 1975 | | |
| Spartina patens | 0-5 | 1888 | 16.8 |
| | 5-10 | 1236 | 49.3 |
| | 10-15 | 376 | 56.0 |
| | 15-35 | 254 | 47.9 |
| | May, 1975 | | |
| Spartina patens | 0-5 | 2133 | 31.2 |
| | 5-10 | 611 | 24.3 |
| | 10-15 | 340 | 61.5 |
| | 15-35 | 426 | 36.3 |

$\bar{X}$ = Mean; CV = Coefficient of Variation.

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# Table A2a

## Underground Biomass Expressed in $g/m^2$ for Depth Zones in Stands of Marsh Plants in Georgia

| Species | June, 1974 | | | July and August, 1974 | | |
|---|---|---|---|---|---|---|
| | Depth (cm) | $\bar{X}$ | CV | Depth (cm) | $\bar{X}$ | CV |
| Borrichia frutescens | 0-5 | 217 | 77.1 | 0-5 | 412 | 45.7 |
| | 5-10 | 525 | 90.3 | 5-10 | 620 | 48.9 |
| | 10-15 | 177 | 121.4 | 10-15 | 127 | 76.4 |
| | 15-35 | 45 | 61.0 | 15-35 | 91 | 43.2 |
| Distichlis spicata | 0-5 | 1757 | 31.7 | 0-5 | 2164 | 43.4 |
| | 5-10 | 611 | 102.4 | 5-10 | 738 | 23.5 |
| | 10-15 | 122 | 55.0 | 10-15 | 254 | 44.8 |
| | 15-35 | 566 | 85.4 | 15-35 | 489 | 67.0 |
| Salicornia virginica | 0-5 | 367 | 26.4 | 0-5 | 308 | 80.7 |
| | 5-10 | 430 | 66.2 | 5-10 | 344 | 70.8 |
| | 10-15 | 118 | 53.3 | 10-15 | 118 | 73.6 |
| | 15-35 | 136 | 76.3 | 15-35 | 118 | 65.8 |
| Spartina cynosuroides *(between) | 0-5 | 143 | 79.8 | 0-5 | 559 | 75.8 |
| | 5-10 | 143 | 79.8 | 5-10 | 152 | 56.4 |
| | 10-15 | 90 | 25.0 | 10-15 | 181 | 43.2 |
| | 15-35 | 974 | 39.1 | 15-35 | 1992 | 69.2 |
| | 35-55 | 980 | 26.8 | 35-55 | 1048 | 65.1 |
| Spartina cynosuroides *(over) | 0-5 | 498 | 65.5 | 0-5 | 1773 | 46.6 |
| | 5-10 | 844 | 62.1 | 5-10 | 2099 | 53.1 |
| | 10-15 | 1103 | 104.9 | 10-15 | 2536 | 58.5 |
| | 15-35 | 2959 | 71.7 | 15-35 | 1795 | 48.9 |
| | 35-55 | 2076 | 40.5 | 35-55 | 1336 | 72.0 |
| Spartina patens | 0-5 | 774 | 45.2 | 0-5 | 919 | 57.7 |
| | 5-10 | 294 | 48.6 | 5-10 | 312 | 47.1 |
| | 10-15 | 195 | 34.5 | 10-15 | 145 | 13.9 |
| | 15-35 | 244 | 40.0 | 15-35 | 240 | 29.7 |
| Sporobolus virginicus | 0-5 | 521 | 105.6 | 0-5 | 543 | 54.6 |
| | 5-10 | 118 | 25.0 | 5-10 | 177 | 89.5 |
| | 10-15 | 118 | 85.4 | 10-15 | 72 | 34.4 |
| | 15-35 | 389 | 65.8 | 15-35 | 208 | 84.7 |

*Over-plant cores were taken with a stem centered in the core and between-plant cores without stems in the core.

$\bar{X}$ = Mean;  CV = Coefficient of Variation.

Table A2b

Underground Biomass Expressed in $g/m^2$ for Depth Zones

in Stands of Marsh Plants in Georgia

| | September, 1974 | | | | November, 1974 | | |
|---|---|---|---|---|---|---|---|
| Species | Depth (cm) | $\bar{V}$ | CV | Species | Depth (cm) | $\bar{V}$ | CV |
| Borrichia frutescens ** | 0-5 | 278 | 139.0 | Distichlis spicata | 0-5 | 1766 | 11.0 |
| | 5-10 | 174 | 27.0 | | 5-10 | 543 | 61.7 |
| | 10-15 | 120 | 125.7 | | 10-15 | 317 | 86.9 |
| | 15-35 | 68 | 88.0 | | 15-35 | 1012 | 53.0 |
| Distichlis spicata ** | 0-5 | 582 | 37.4 | | 0-5 | 731 | 76.9 |
| | 5-10 | 317 | 51.5 | | 5-10 | 210 | 53.0 |
| | 10-15 | 165 | 39.6 | | 10-15 | 204 | 106.0 |
| | 15-35 | 378 | 39.0 | | 15-35 | 333 | 23.9 |
| Spartina cynosuroides | 0-5 | 113 | 20.0 | Distichlis spicata ** | 0-5 | 754 | 16.6 |
| | 5-10 | 376 | 158.2 | | 5-10 | 136 | 60.0 |
| | 10-15 | 505 | 110.2 | | 10-15 | 61 | 21.5 |
| | 15-35 | 770 | 16.4 | | 15-35 | 582 | 34.9 |
| | 35-55 | 2973 | 60.6 | Salicornia virginica | 0-5 | 408 | 57.7 |
| | | | | | 5-10 | 272 | 43.3 |
| | | | | | 10-15 | 158 | 111.6 |
| | | | | | 15-35 | 129 | 10.2 |
| Spartina cynosuroides *(over) | 0-5 | 1669 | 36.6 | | | | |
| | 5-10 | 2226 | 35.8 | Salicornia virginica ** | 0-5 | 657 | 62.9 |
| | 10-15 | 2355 | 31.4 | | 5-10 | 401 | 32.6 |
| | 15-35 | 4709 | 26.2 | | 10-15 | 165 | 55.3 |
| | 35-55 | 6482 | 24.9 | | 15-35 | 215 | 67.0 |
| | | | | Salicornia virginica ** | 0-5 | 340 | 37.1 |
| | | | | | 5-10 | 23 | 0.0 |
| | | | | | 10-15 | 23 | 0.0 |
| | | | | | 15-35 | 16 | 82.9 |

(Continued)

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Table A2b (Concluded)

| Species | September, 1974 | | | Species | November, 1974 | | |
| | Depth (cm) | $\bar{V}$ | CV | | Depth (cm) | $\bar{V}$ | CV |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sporobolus virginicus | 0-5 | 616 | 22.7 | | 0-5 | 641 | 32.0 |
| | 5-10 | 294 | 36.! | | 5-10 | 226 | 34.6 |
| | 10-15 | 158 | 66.3 | | 10-15 | 91 | 66.0 |
| | 15-35 | 638 | 38.2 | | 15-35 | 641 | 60.8 |
| | | | | Sporobolus virginicus ** | 0-5 | 482 | 42.6 |
| | | | | | 5-10 | 84 | 56.2 |
| | | | | | 10-15 | 52 | 100.4 |
| | | | | | 15-35 | 226 | 155.9 |
| | | | | Sporobolus virginicus ** | 0-5 | 378 | 22.7 |
| | | | | | 5-10 | 45 | 50.0 |
| | | | | | 10-15 | 23 | 0.0 |
| | | | | | 15-35 | 23 | 0.0 |

**Cores taken from other than original stand for comparative purposes.

$\bar{X}$ = Mean;  CV = Coefficient of Variation.

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## Table A2c
### Underground Biomass Expressed in $q/m^2$ for Depth Zones
### in Stands of Marsh Plants in Georgia

| | December, 1974 | | | | January, 1975 | | |
| Species | Depth (cm) | $\bar{V}$ | CV | Species | Depth (cm) | $\bar{V}$ | CV |
|---|---|---|---|---|---|---|---|
| Borrichia frutescens | 0-5 | 131 | 132.1 | | 0-5 | 136 | 76.3 |
| | 5-10 | 240 | 69.2 | | 5-10 | 113 | 69.2 |
| | 10-15 | 63 | 30.0 | | 10-15 | 91 | 43.2 |
| | 15-35 | 127 | 104.6 | | 15-35 | 129 | 53.7 |
| | | | | Borrichia frutescens ** | 0-5 | 91 | 90.0 |
| | | | | | 5-10 | 106 | 24.5 |
| | | | | | 10-15 | 75 | 46.4 |
| | | | | | 15-35 | 106 | 117.2 |
| Salicornia virginica | 0-5 | 326 | 35.6 | | 0-5 | 290 | 63.6 |
| | 5-10 | 217 | 59.2 | | 5-10 | 267 | 22.0 |
| | 10-15 | 91 | 84.8 | | 10-15 | 122 | 67.6 |
| | 15-35 | 68 | 57.7 | | 15-35 | 122 | 59.4 |
| | | | | Spartina cynosuroides *(between) | 0-5 | 152 | 94.8 |
| | | | | | 5-10 | 346 | 111.4 |
| | | | | | 10-15 | 220 | 145.9 |
| | | | | | 15-35 | 1229 | 139.9 |
| | | | | | 35-55 | 3570 | 38.6 |
| | | | | Spartina cynosuroides *(over) | 0-5 | 446 | 46.0 |
| | | | | | 5-10 | 355 | 37.3 |
| | | | | | 10-15 | 718 | 76.1 |
| | | | | | 15-35 | 1895 | 31.2 |
| | | | | | 35-55 | 3978 | 82.7 |
| | | | | Spartina patens | 0-5 | 1080 | 24.5 |
| | | | | | 5-10 | 249 | 9.1 |
| | | | | | 10-15 | 143 | 24.3 |
| | | | | | 15-35 | 181 | 37.5 |
| | | | | Spartina patens ** | 0-5 | 181 | 21.6 |
| | | | | | 5-10 | 120 | 28.9 |
| | | | | | 10-15 | 52 | 50.0 |
| | | | | | 15-35 | 272 | 25.0 |

*Over-plant cores were taken with a stem centered in the core and
between-plant cores without stems in the core.
**Cores taken from different stands for comparative purposes.

$\bar{X}$ = Mean;  CV = Coefficient of Variation.

## Table A3a

Underground Biomass Expressed in g/m² for Depth Zones in Stands of Marsh Plants in Maine

| Species | June, 1974 Depth (cm) | X̄ | CV | July and August, 1974 Depth (cm) | X̄ | CV | September, 1974 Depth (cm) | X̄ | CV |
|---|---|---|---|---|---|---|---|---|---|
| Carex paleacea | 0-5 | 1886 | 37.7 | 0-5 | 2318 | 35.6 | 0-5 | 2472 | 26.6 |
| | 5-10 | 2056 | 18.5 | 5-10 | 2803 | 19.4 | 5-10 | 2930 | 17.9 |
| | 10-15 | 1852 | 24.1 | 10-15 | 2151 | 70.9 | 10-15 | 2594 | 15.9 |
| | 15-35 | 6416 | 27.1 | 15-35 | 6353 | 42.0 | 15-35 | 7666 | 3.1 |
| | 35-55 | 4084 | 39.2 | 35-55 | 5311 | 37.8 | 35-55 | 5588 | 42.0 |
| Juncus gerardi | 0-5 | 1942 | 28.0 | 0-5 | 1721 | 48.1 | 0-5 | 2798 | 17.1 |
| | 5-10 | 1897 | 57.8 | 5-10 | 1234 | 33.8 | 5-10 | 1064 | 11.6 |
| | 10-15 | 2355 | 26.9 | 10-15 | 1381 | 24.0 | 10-15 | 901 | 26.4 |
| | 15-35 | 4206 | 59.2 | 15-35 | 5221 | 74.2 | 15-35 | 2087 | 93.0 |
| Spartina alterniflora (creekbank) | 0-5 | 1970 | 42.9 | 0-5 | 2169 | 23.0 | 0-5 | 1752 | 46.0 |
| | 5-10 | 2921 | 3.3 | 5-10 | 2780 | 25.7 | 5-10 | 2594 | 11.6 |
| | 10-15 | 1780 | 17.9 | 10-15 | 1784 | 11.6 | 10-15 | 1616 | 6.9 |
| | 15-35 | 5307 | 78.3 | 15-35 | 7055 | 11.7 | 15-35 | 5981 | 16.0 |
| Spartina alterniflora (High marsh) | 0-5 | 1191 | 37.0 | 0-5 | 937 | 16.4 | 0-5 | 896 | 27.0 |
| | 5-10 | 878 | 38.8 | 5-10 | 833 | 14.3 | 5-10 | 865 | 29.7 |
| | 10-15 | 367 | 35.5 | 10-15 | 566 | 24.6 | 10-15 | 340 | 22.. |
| | 15-35 | 1358 | 56.9 | 15-35 | 1693 | 46.8 | 15-35 | 1399 | 27.4 |
| | 35-55 | 919 | 99.0 | 35-55 | 910 | 135.2 | 35-55 | 1653 | 47.9 |
| Spartina patens | 0-5 | 1227 | 16.1 | 0-5 | 1236 | 10.2 | 0-5 | 1739 | 22.3 |
| | 5-10 | 1621 | 10.8 | 5-10 | 1494 | 22.9 | 5-10 | 1168 | 55.5 |
| | 10-15 | 1793 | 20.4 | 10-15 | 1390 | 33.2 | 10-15 | 1404 | 30.7 |
| | 15-35 | 3844 | 14.6 | 15-35 | 3663 | 17.8 | 15-35 | 4057 | 31.1 |
| | 35-55 | 3518 | 24.0 | 35-55 | 2106 | 13.9 | 35-55 | 2404 | 25.7 |

X̄ = Mean; CV = Coefficient of Variation.

## Table A3b

### Underground Biomass Expressed in $q/m^2$ for Depth Zones in Stands of Marsh Plants in Maine

| Species | Depth (cm) | $\bar{X}$ | CV |
|---------|------------|-----------|-----|
| **April, 1975** | | | |
| Juncus gerardi | 0-5 | 1856 | 35.0 |
| | 5-10 | 1277 | 15.2 |
| | 10-15 | 1413 | 65.6 |
| Spartina alterniflora (creekbank) | 0-5 | 1884 | 18.6 |
| | 5-10 | 2201 | 11.9 |
| | 10-15 | 1684 | 15.0 |
| | 15-35 | 5452 | 15.3 |
| Spartina alterniflora (high marsh) | 0-5 | 992 | 9.8 |
| | 5-10 | 1114 | 49.0 |
| | 10-15 | 466 | 26.3 |
| | 15-35 | 2155 | 35.6 |
| | 35-55 | 1204 | 78.3 |
| Spartina patens | 0-5 | 1361 | 28.9 |
| | 5-10 | 1186 | 21.4 |
| | 10-15 | 1019 | 6.5 |
| **May, 1975** | | | |
| Spartina patens | 0-5 | 1449 | 20.4 |
| | 5-10 | 1182 | 12.2 |
| | 10-15 | 1376 | 10.6 |
| | 15-35 | 4098 | 14.6 |
| | 35-55 | 2431 | 32.3 |

$\bar{X}$ = Mean;  CV = Coefficient of Variation.

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APPENDIX B: MINERAL COMPOSITION OF UNDERGROUND MACRO-ORGANIC MATTER

## Table B1a

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Borrichia frutescens in Georgia

| Month | Depth (cm) | % | | | | | PPM | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | Mn | Cu | Zn |
| Feb. | 0-35 | 0.78(0)* | 0.19(.01) | 1.2...16) | 0.16(.09) | 0.26(.03) | 74(4) | 12(7) | 29(0) |
| June | 0-35 | 1.02(.10) | 0.13(.01) | 1.30(.06) | 0.34(.08) | 0.30(.01) | 59(6) | 15(3) | 52(6) |

* Numbers in parentheses are standard errors.
  (n = 5).

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## Table B1b

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Distichlis spicata in Georgia

| | Depth | | | % | | | | PPM | |
|---|---|---|---|---|---|---|---|---|---|
| Month | (cm) | N | P | K | Ca | Mg | Mn | Cu | Zn |
| Feb. | 0-5 | 1.25(.08) | 0.10(.17) | 0.40(.05) | 0.20(.07) | 0.30(.02) | 8(4) | 14(2) | 29(15) |
| | 5-35 | 1.44(.05) | 0.04(.01) | 0.30(0) | 0.30(.02) | 0.30(.02) | 2(1) | 39(4) | 21(4.) |
| June | 0-35 | 1.17(.12) | 0.01(0) | 0.02(.01) | 0.20(0) | 0.30(.01) | 6(2) | 25(6) | 54(23) |
| Nov. | 0-35 | 1.25(.05) | 0.04(.01) | 0.11(.05) | 0.20(.05) | 0.40(.01) | 22(5) | 22(4) | 11(2) |

* Numbers in parentheses are standard errors.
  (n = 5).

Table B1c

Mineral Composition of Underground Macro-Organic Matter

In a Stand of Salicornia virginica in Georgia

| Month | Depth (cm) | % | | | | | | PPM | | |
| | | N | P | K | Ca | Mg | Mn | Cu | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Feb. | 0-35 | 1.21(.10)* | 0.09(.01) | 0.53(.07) | 0.36(.10) | 0.34(.02) | 104(11) | 3(1) | 36(8) |
| June | 0-35 | 1.21(.08) | 0.08(.01) | 0.43(.05) | 0.39(.06) | 0.43(.03) | 142(27) | 7(2) | 104(35) |
| Nov. | 0-35 | 1.07(.07) | 0.10(.02) | 0.11(.08) | 0.39(.06) | 0.39(.03) | 40(7) | 5(0) | 34(9) |

* Numbers in parentheses are standard errors.
  (n = 5).

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## Table 8!d

## Mineral Composition of Underground Macro-Organic Matter

## In a Stand of Spartina cynosuroides in Georgia

| Month | Depth (cm) | % | | | | | PPM | | |
|-------|-----------|------|------|------|------|------|---------|------|--------|
| | | N | P | K | Ca | Mg | Mn | Cu | Zn |
| Feb. | 0-15 | 0.92(.03)* | 0.11(0) | 0.33(.06) | 0.60(.14) | 0.17(.03) | 382(123) | 5(1) | 22(8) |
| | 15-45 | 1.02(.03) | 0.11(.02) | 0.28(.06) | 0.65(.10) | 0.16(.02) | 262(51) | 3(1) | 48(17) |
| June | 0-15 | 0.99(.03) | 0.17(.02) | 0.49(.15) | 0.40(.16) | 0.17(.01) | 229(57) | 7(1) | 41(15) |
| | 15-55 | 0.78(.03) | 0.11(.02) | 0.30(.08) | 0.69(.21) | 0.16(.01) | 237(31) | 7(2) | 33(11) |

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* Numbers in parentheses are standard errors.
  (n = 5).

Table B1e

## Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Spartina patens in Georgia

| Month | Depth (cm) | N | P | % K | Ca | Mg | Mn | PPM Cu | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Feb. | 0-35 | 0.82(.05)* | 0.12(.04) | 0.27(.14) | 0.44(.17) | 0.23(.17) | 52(10) | 5(3) | 129(85) |
| June | 0-35 | 0.81(.04) | 0.13(.02) | 0.34(.05) | 0.24(.02) | 0.22(.01) | 51(2) | 5(0) | 106(10) |

\* Numbers in parentheses are standard errors.
  (n = 5).

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Table B1f

## Mineral Composition of Underground Macro-Organic Matter

## In a Stand of Sporobolus virginicus in Georgia

| Month | Depth (cm) | % | | | | | Mn | PPM | |
|-------|------------|-----------|----------|----------|----------|----------|--------|-------|---------|
| | | N | P | K | Ca | Mg | | Cu | Zn |
| Feb. | 0-35 | 0.86(.03)* | 0.08(.01) | 0.31(.03) | 0.39(.02) | 0.24(.02) | 39(13) | 7(3) | 58(19) |
| June | 0-35 | 0.94(1.0) | 0.04(.01) | 0.17(.06) | 0.36(.07) | 0.28(.02) | 27(4) | 10(4) | 125(24) |
| Nov. | 0-35 | 0.81(.11) | 0.05(.01) | 0.10(.09) | 0.21(.06) | 0.23(.04) | 31(1) | 6(0) | 19(2) |

\* Numbers in parentheses are standard errors.
(n = 5).

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## Table B2a

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Distichlis spicata in Delaware

| Month | Depth (cm) | N | P | % K | Ca | Mg | Mn | PPM Cu | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Feb. | 0-5 | 1.39(.04)* | 0.13(.02) | 0.35(.09) | 0.31(.14) | 0.26(.04) | 20(10) | 17(7) | 179(33) |
| | 5-10 | 1.18(.09) | 0.08(.03) | 0.34(.09) | 0.26(.03) | 0.32(.02) | 20(4) | 20(9) | 140(122) |
| | 10-15 | 1.00(.16) | 0.03(.03) | 0.19(.10) | 0.21(.03) | 0.28(.07) | 9(4) | 16(9) | 36(16) |
| | 15-35 | 0.98(.04) | 0.01(.01) | 0.08(.14) | 0.22(.08) | 0.22(.05) | 20(4) | 5(4) | 45(32) |
| June | 0-5 | 1.33(.11) | 0.15(.07) | 0.33(.05) | 0.20(.04) | 0.25(.06) | 31(7) | 13(4) | 159(66) |
| | 5-10 | 1.35(.11) | 0.10(.04) | 0.25(.05) | 0.24(.04) | 0.32(.03) | 32(3) | 22(4) | 64(14) |
| | 10-15 | 1.39(.10) | 0.08(.03) | 0.20(.03) | 0.34(.05) | 0.33(.03) | 29(2) | 20(2) | 40(14) |
| | 15-35 | 0.91(.14) | 0.02(.02) | 0.08(.03) | 0.24(.10) | 0.19(.08) | 14(8) | 6(2) | 39(14) |
| Nov. | 0-5 | 1.45(.07) | 0.12(.06) | 0.34(.17) | 0.43(.13) | 0.34(.08) | 25(9) | 17(9) | 84(15) |
| | 5-10 | 1.27(.04) | 0.06(.03) | 0.25(.13) | 0.35(.03) | 0.39(.03) | 16(5) | 21(11) | 26(12) |
| | 10-15 | 1.30(.24) | 0.07(.02) | 0.27(.10) | 0.36(.04) | 0.26(.04) | 18(2) | 18(6) | 22(6) |
| | 15-35 | 0.75(.06) | 0.08(.04) | 0.15(.14) | 0.31(.10) | 0.23(.06) | 27(16) | 11(7) | 24(13) |

* Numbers in parentheses are standard errors.
(n = 5).

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## Table B2b

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Juncus gerardi in Delaware

| Month | Depth (cm) | % | | | | | Mn | PPM | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | | Cu | Zn |
| Feb. | 0-5 | 1.32(.04)* | 0.20(.01) | 0.50(.06) | 0.40(.05) | 0.30(.01) | 74(12) | 4(0) | 34(3) |
| | 5-45 | 0.78(.03) | 0.08(.01) | 0.70(.05) | 0.20(.04) | 0.20(.02) | 41(6) | 4(1) | 36(11) |
| June | 0-5 | 1.19(.06) | 0.10(.01) | 0.20(.04) | 0.20(.04) | 0.20(.03) | 175(43) | 6(1) | 62(14) |
| | 5-15 | 0.58(.06) | 0.05(.01) | 0.40(.05) | 0.10(.02) | 0.20(.01) | 55(8) | 2(1) | 36(13) |
| | 15-45 | 0.60(.05) | 0.05(.01) | 0.30(.05) | 0.10(.02) | 0.15(.02) | 28(5) | 4(2) | 21(4) |
| Nov. | 0-5 | 1.48(.06) | 0.10(.01) | 0.50(.05) | 0.40(.01) | 0.20(.03) | 133(45) | 6(2) | 114(48) |
| | 5-15 | 0.87(.06) | 0.08(.01) | 0.50(.01) | 0.20(.02) | 0.20(.01) | 33(2) | 1(0) | 39(10) |
| | 15-55 | 0.60(.05) | 0.07(.01) | 0.70(.07) | 0.10(.04) | 0.20(.02) | 24(3) | 1(0) | 19(8) |

* Numbers in parentheses are standard errors.
  (n = 5).

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Table B2c

Mineral Composition of Underground Macro-Organic Matter

In a Stand of Phragmites communis In Delaware

| Month | Depth (cm) | % | | | | | Mn | PPM | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | | Cu | Zn |
| Feb. | 0-35 | 1.23(.05)* | 0.06(.01) | 0.26(.07) | 0.27(.04) | 0.17(.02) | 34(6) | 18(3) | 65(4) |
| | 35-71 | 0.93(.02) | 0.05(.01) | 0.0 (0) | 0.24(.04) | 0.14(.01) | 15(2) | 18(2) | 94(13) |
| June | 0-10 | 1.09(.06) | 0.09(.01) | 0.41(.02) | 0.06(.03) | 0.12(.02) | 47(5) | 10(5) | 73(16) |
| | 10-35 | 0.94(.10) | 0.12(.02) | 0.70(.18) | 0.05(.02) | 0.11(.01) | 22(3) | 11(7) | 35(8) |
| | 35-75 | 0.68(.13) | 0.07(.01) | 0.21(.05) | 0.15(.04) | 0.11(.01) | 21(4) | 23(5) | 58(22) |

* Numbers in parentheses are standard errors. (n = 5).

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## Table B2d

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Salicornia virginica in Delaware

| Month | Depth (cm) | % | | | | | PPM | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | Mn | Cu | Zn |
| Feb. | 0-5 | 1.86(0)* | 0.19(.03) | 0.53(.02) | 0.41(.03) | 0.42(.11) | 64(8) | 12(2) | 128(67) |
| | 5-35 | 1.46(.27) | 0.11(.03) | 0.44(.20) | 0.23(.15) | 0.33(.04) | 66(14) | 8(2) | 71(45) |
| June | 0-5 | 1.72(.09) | 0.14(.01) | 0.42(.03) | 0.48(.03) | 0.37(.02) | 81(9) | 11(1) | 85(19) |
| | 5-35 | 1.07(.12) | 0.06(.01) | 0.24(.03) | 0.24(.04) | 0.21(.01) | 38(4) | 9(2) | 58(31) |

* Numbers in parentheses are standard errors.
  (n = 5).

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**Table B2e**

**Mineral Composition of Underground Macro-Organic Matter**

**In a Stand of Spartina patens in Delaware**

| Month | Depth (cm) | N | P | K | Ca | Mg | Mn | Cu | Zn |
|-------|-----------|------|------|------|------|------|------|------|------|
| Sept. | 0-5 | 0.93(.04)* | 0.08(0) | 0.42(.02) | 0.20(.01) | 0.12(.01) | 27(2) | 3(0) | 9(6) |
|       | 5-35 | 0.51(.04) | 0.06(.01) | 0.38(.09) | 0.13(.01) | 0.08(.02) | 16(3) | 4(2) | 48(25) |

\* Numbers in parentheses are standard errors. (n = 5).

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## Table B3a

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Spartina alterniflora in Maine

| Month | Depth (cm) | % | | | | | PPM | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | Mn | Cu | Zn |
| June | 0-5 | 1.23(.12)* | 0.11(.02) | 0.61(.14) | 0.25(.06) | 0.25(.02) | 33(6) | 5(1) | 39(4) |
| | 5-10 | 0.98(.06) | 0.05(0) | 0.12(.03) | 0.17(.03) | 0.20(.02) | 22(4) | 3(1) | 29(7) |
| | 10-15 | 1.06(.03) | 0.07(.01) | 0.29(.05) | 0.26(.02) | 0.26(.01) | 22(2) | 5(1) | 41(6) |
| | 15-31 | 0.81(.10) | 0.05(.01) | 0.09(.03) | 0.25(.04) | 0.20(.02) | 49(5) | 5(2) | 37(10) |

* Numbers in parentheses are standard errors. (n = 5).

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## Table B3b

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Juncus gerardi in Maine

| Month | Depth (cm) | N | P | % K | Ca | Mg | Mn | PPM Cu | Zn |
|---|---|---|---|---|---|---|---|---|---|
| June | 0-5 | 1.31(.03)* | 0.10(.01) | 0.40(.08) | 0.30(.02) | 0.30(.02) | 53(5) | 4(1) | 39(14) |
| | 5-10 | 1.21(.02) | 0.10(0) | 0.30(.06) | 0.30(.03) | 0.20(.01) | 24(4) | 5(1) | 14(3) |
| | 10-15 | 0.99(.44) | 0.10(.01) | 0.20(.05) | 0.20(.05) | 0.20(.02) | 18(3) | 5(2) | 9(3) |
| | 15-30 | 0.96(.08) | 0.05(.01) | 0.20(.03) | 0.30(.04) | 0.20(.03) | 38(4) | 6(2) | 25(5) |

* Numbers in parentheses are standard errors. (n = 5).

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## Table B3c

### Mineral Composition of Underground Macro-Organic Matter

### In a Stand of Spartina patens in Maine

| Month | Depth (cm) | % | | | | | Mn | PPM | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | Mn | Cu | Zn |
| June | 0-5 | 1.50(.14)* | 0.13(.02) | 0.38(.04) | 0.31(.08) | 0.24(.02) | 37(8) | 8(4) | 85(10) |
| | 5-10 | 1.51(.01) | 0.08(0) | 0.17(.06) | 0.34(.05) | 0.28(.02) | 25(3) | 6(2) | 29(7) |
| | 10-15 | 1.45(.07) | 0.05(0) | 0.12(.03) | 0.25(.03) | 0.25(.03) | 23(4) | 4(2) | 34(2) |
| | 15-35 | 1.12(.05) | 0.06(.01) | 0.15(.07) | 0.30(.03) | 0.24(.03) | 34(9) | 3(1) | 52(22) |
| | 35-53 | 1.11(.02) | 0.06(0) | 0.17(.04) | 0.31(.02) | 0.23(.02) | 28(3) | 5(2) | 58(14) |

* Numbers in parentheses are standard errors.
  (n = 5).

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APPENDIX C: SOIL PROFILE DESCRIPTIONS

Table C1

Soil Profile Description for Soils Supporting Tidal Marsh Plants in Georgia

| Vegetation | Horizon depth (cm) | Color | Texture | Mottles | Structure & Consistency | Reaction | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Borrichia frutescens | A1 0-4 | Very dark gray 10YR 3/1 | Sandy clay loam | Common fine faint dark grey | Massive, slightly sticky | pH 8.5 | Clear wavy | Borrichia rhizomes, Fiddler Crab burrows, N-value <0.7 |
|  | C1g 4-28 | Grayish brown 2.5Y 5/2 | Sandy clay loam | Common medium faint olive grey 5Y 5/2 | Massive, slightly sticky | pH 6.6 | Gradual wavy | Few small roots, N-value <0.7 |
|  | C2g 28-64 | Gray 5Y 6/1 | Light sandy clay loam | Many coarse prominent very dark grayish brown 10YR 3/2 | Massive, slightly sticky | pH 7.8 | Gradual wavy | Few small roots, few small sand pockets, N-value <0.7 |
|  | C3g 64-125+ | Gray 5Y 5/1 and dark gray 5Y 4/1 | Sandy loam |  | Massive, non-sticky | pH 8.0 |  | N-value <0.7 |
| Distichlis spicata | A11 0-37 | Black N 2/ | Loam |  | Massive, slightly sticky | pH 8.8 | Gradual wavy | Many small roots, N-value <0.7 |
|  | A12 37-100 | Black N 2/ | Loam |  | Massive, slightly sticky | pH 8.4 | Gradual wavy | Many small roots, N-value <0.7 |
|  | C1g 100-150+ | Very dark grayish brown 10YR 3/2 | Sandy loam |  | Massive, non-sticky | pH 8.6 | Gradual wavy | Few small roots, N-value <0.7 |
| Salicornia virginica | A1 0-7 | Light brownish gray 2.5Y 6/2 | Fine sand | Few fine prominent yellowish brown | Single grained, loose | pH 7.3 | Gradual wavy | Few small, mostly live fibrous roots, N-value <0.7 |
|  | C1g 7-32 | Light brownish gray 10YR 6/2 | Fine sand | Common medium prominent brown 10YR 5/3 and medium faint light grey 10YR 7/1 | Single grained, loose | pH 7.4 | Gradual wavy | N-value <0.7 |

(Continued)

Table C1 (Continued)

| Vegetation | Horizon depth (cm) | Color | Texture | Mottles | Structure & Consistency | Reaction | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Salicornia virginica | C2g 32-80 | Light gray 10YR 6/1 | Fine sand | Few large prominent yellowish brown 10YR 5/6 | Single grained, loose | pH 7.6 | Clear wavy | N-value <0.7 |
| | C3g 80-150+ | Greenish gray 5GY 5/1 | Sandy clay loam | Few small pockets of gray (5Y 5/1) and dark gray (5Y 4/1) sandy loam and loamy sand | Massive, friable | pH 8.7 | | Few small dead fibrous roots, N-value <0.7 |
| Spartina cynosuroides | A1 0-5 | Brown to dark brown 10YR 4/3 | Loamy sand | Common fine and medium distinct light brownish gray 2.5Y 6/2 | Single grained, loose | pH 7.0 | Abrupt smooth | Common fine grass roots and many large rhizomes |
| | C1g 5-20 | Grayish brown 10YR 5/2 | Sandy clay loam | Many fine distinct yellowish brown (10YR 5/6) and many fine faint gray (5Y 5/1) | Massive, friable | pH 7.0 | Gradual wavy | Common small grass roots and few large rhizomes, common small sand pockets |
| | C2g 20-52 | Gray to dark gray 5Y 5/1 | Sandy clay loam | Common medium, prominent dark yellowish brown 10YR 5/6 | Massive, friable | pH 7.1 | Clear wavy | Common small grass roots, small sand pockets |
| | C3g 52-85 | Dark gray N 4/ | Silty clay loam | | Massive, sticky | pH 7.0 | Gradual wavy | N-value <0.7, about 40% decaying grass roots, stems, and leaves, giving the layer a putrid odor |
| | C4g 85-150 | Dark gray 5GY 4/1 | Loamy sand | | Single grained, loose | pH 7.1 | | |

(Continued)

Table C1 (Concluded)

| Vegetation | Horizon depth (cm) | Color | Texture | Mottles | Structure & Consistency | Reaction | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Spartina patens | A1 0-25 | Very dark gray 10YR 3/1 | Loamy sand | Few fine prominent dark brown mottles | Single grained, loose to very friable | pH 7.1 | Clear wavy | Many small grass roots, N-value <0.7 |
| | C1g 25-47 | Dark gray 10YR 4/1 | Sand | Few medium faint gray | Single grained, loose | pH 7.5 | Clear wavy | Common small grass roots; N-value <0.7, some uncoated sand grains |
| | C2 47-130 | Dark reddish brown 10YR 3/1 | Loamy sand | | Massive, slightly compacted in place but very friable after removing | pH 7.2 Dry pH 7.0 Wet | Abrupt wavy | Slight odor of $H_2S$ gas, few medium grass roots, N-value <0.7 |
| | C3g 130-160 | Gray 5GY 6/1 | Fine sand | | Single grained, loose | pH 7.0 | | Few small grass roots, N-value <0.7 |
| Spartina virginicus | A11 0-3 | Light gray 5Y 7/1 and gray 5Y 6/1 | Sand | | Single grained, loose | pH 6.8 | Abrupt smooth | Many small grass roots, N-value <0.7 |
| | A12 3-13 | Very dark gray 10YR 3/1 and black 10YR 2/1 | Sand | | Single grained, loose | pH 7.0 | Clear wavy | Common small grass roots, N-value <0.7 |
| | C1g 13-34 | Gray 5YR 5/1 and light gray 5YR 6/1 | Sand | | Single grained, loose | pH 6.8 | Gradual wavy | Few small grass roots, N-value <0.7 |
| | C2g 34-150+ | Dark reddish brown 5YR 2/2 | Sand | | Massive, friable to none | pH 7.3 | | Common medium grass roots, N-value <0.7 |

Table C2

Soil Profile Description for Soils Supporting Tidal Marsh Plants in Delaware

| Vegetation | Horizon depth (cm) | Color | Texture | Structure & Consistency | Reaction | Remarks |
|---|---|---|---|---|---|---|
| Distichlis spicata | 0-19 | Dark gray | Silt loam | Structureless; plastic and slightly sticky | pH 6.7 | Organic matter - mostly roots |
| | 19-29 | Gray | Sandy clay | | pH 7.7 | Many decomposed roots producing dark streaks; some lighter colored roots. |
| | 29-45 | Gray, brownish streaks | Sandy clay loam | Plastic-slightly sticky, some indication of weak structure | pH 7.8 | |
| | 45-75+ | Mottled gray and yellow | Sandy clay loam | Slightly plastic, non-sticky | pH 7.2 | |
| Salicornia virginica | 0-8 | Black top 1/2 cm, grey 1 cm, top grades to mottled gray/brown | Sandy loam | Slightly plastic, non-sticky | pH 7.5 | Many fibrous roots; single grained |
| | 8-53 | Mottled gray red-brownish 50% (5YR) | Sandy loam | | pH 7.8 | Many disintegrated root channels; oxidized material appears to follow old root channels |
| | 53-70 | Gray w/some red-brown mottling (15-20%) | More clay (not great) sandy clay loam | | pH 7.3 | Less oxidation |
| | 70+ | Gray | Sand | Hard in place, loose when removed | pH 7.5 | |

(Continued)

Table C2 (Continued)

| Vegetation | Horizon depth (cm) | Color | Texture | Structures & Consistency | Reaction | Remarks |
|---|---|---|---|---|---|---|
| Spartina patens and Distichlis spicata mixed | 0-15 | Gray-brown | Silty clay loam | Fibrous mat | | not area |
| | 15-35 | Gray | Silty clay loam | Structureless, slightly sticky, plastic | | Many fibrous roots |
| | 35-65 | Dark gray black | Clay loam | Structureless, slightly sticky, plastic | | Many roots, more roots than layer above it; old earlier surface appears again |
| | 65-100+ | Gray | Sandy loam | Massive, very plastic, slightly sticky | | Some roots |
| Juncus gerardi | 0-20 | Gray | Sandy clay | Structureless, slightly sticky, slightly plastic | pH 6.8 | Many fibrous roots |
| | 20-30 | Gray, some red-brown mottling | Sandy clay | Weak sub-angular, blocky structure | pH 6.9 | Many fibrous roots |
| | 30-50 | Yellowish-brown 10YR 56 | Sandy clay loam | Weak medium, sub-angular blocky structure | pH 7.1 | Many fibrous roots, no gray, better drained |
| | 50-80 | Yellowish-brown (10YR) mottled w/some gray | Sandy clay | Weak angular blocky structure | pH 7.2 | |
| | 80-90 | | Sand | | | Grading to loose sand at 90 cm |

(Continued)

Table C2 (Concluded)

| Vegetation | Horizon depth (cm) | Color | Texture | Structure & Consistency | Reaction | Remarks |
|---|---|---|---|---|---|---|
| Pinegrass community | 0-25 | Grey | Silty clay loam | Slightly sticky, slightly plastic, some angular structure | pH 7.1 | Root mass numerous |
|  | 25-75 | Grey mottled w/some red brown | Sandy clay loam | Massive, structureless, slightly sticky, non-plastic | pH 6.4 | Still considerable roots throughout horizon |
|  | 75+ | Grey | Sandy clay loam | Massive, slightly sticky, non-plastic | pH 6.3 | A few roots; root channel lined with brownish red |

Table C3

Soil Profile Description for Soils Supporting Tidal Marsh Plants in Maine

| Vegetation | Horizon Depth (cm) | Color | Texture | Mottles | Structure & Consistency | Reaction | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Carex paleacea | O2 0-23 | Gray 10YR 5/1 | Mucky silt | | Massive Slightly sticky, plastic | pH 6.4 | Abrupt smooth | Many roots |
| | C1g 23-46 | Gray 5Y 5/1 | Silt | | Massive Slightly sticky, plastic | pH 6.8 | Abrupt smooth | No live roots, 50% by volume dead plant material |
| | C2g 46-71 | Dark greenish gray 5GY 4/1 | Silt | | Massive Slightly sticky, plastic | pH 7.2 | Abrupt smooth | 30% by volume dead plant material, thin (<1/4") lens of sand and some bark |
| | C3g 71-96 | Dark greenish gray 5GY 4/1 | Silt | | Massive Slightly sticky, plastic | pH 7.5 | | 30% by volume dead plant material |
| Juncus gerardi | A11 0-3 | Light gray/gray 5Y 6/1 with 30% black 10YR 2.5/1 | Silt loam | | Massive Firm, slightly sticky, plastic | pH 7.0 | Abrupt irregular | Many fine and medium roots |
| | A12 3-8 | Very dark gray 10YR 3/1 | Silt loam | | Moderate very fine and fine granular structure Friable, slightly sticky, plastic | pH 6.3 | Abrupt smooth | High in organic matter Many fine and medium roots |
| | A13 8-15 | Dark gray N4/ | Silty clay loam | Common coarse prominent yellowish red 5YR 4/6 | Moderate fine granular structure along roots Firm, sticky, plastic | pH 6.2 | Abrupt smooth | Many fine and medium roots |

(Continued)

Table C3 (Continued)

| Vegetation | Horizon depth (cm) | Color | Texture | Mottles | Structure & Consistency | Reaction | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Juncus gerardi | A1k 15-25 | Gray 5Y 5/1 | Silt loam | Common coarse prominent yellowish red 5YR 5/6 | Massive Firm, slightly sticky, plastic | pH 5.6 | Abrupt smooth | Many medium roots |
| | A21g 25-30 | Gray 10YR 5/1 | Silt loam | Common medium prominent brown to dark brown 7.5 YR 4/4 | Massive Slightly sticky, plastic | pH 5.6 | Abrupt smooth | Many medium roots |
| | A22g 30-43 | Greenish gray 5GY 6/1 | Silt loam | Common fine prominent yellowish brown (10YR 5/6) along old root channels | Massive Firm, sticky, plastic | pH 5.0 | Abrupt smooth | Few medium roots |
| | C1g 43-89 | Greenish gray 5BG 5/1 | Silty clay | Few fine prominent yellowish red (5 YR 5/8) along old root channels | Massive Firm, sticky, very plastic | pH 5.8 | Abrupt smooth | Very few roots |
| | C2g 89-116 | Greenish gray 5 BG 5/1 and olive 5Y 5/3 | Silty clay | | Weak fine and medium plates separating to moderate very fine angular blocks Firm, sticky, plastic | pH 6.5 | | No live roots, some fine dead roots along ped faces. Black (5YR 2/1). Stains in dendritic patterns on ped faces |

(Continued)

Table C3 (Continued)

| Vegetation | Horizon depth (cm) | Color | Texture | Mottles | Structures & Consistency | Reaction | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Spartina alterniflora (creekbank) | A11 0-13 | Olive gray 5Y 4/2 | Silt loam | | Massive Sticky | pH 6.6 | Abrupt smooth | About 85% roots by volume |
| | A12 13-28 | Very dark gray 5Y 3/1 | Silt loam | | Massive Sticky, plastic | pH 6.8 | Abrupt smooth | Layers of olive colored roots constituting 75% of volume |
| | IIC2B 28-41 | Dark gray N 4/ | Silt loam with globs of gray clay (N 5/) | | Massive Very sticky, very plastic | pH 7.0 | Abrupt smooth | About 30% roots by volume |
| | IIIC1g 41-91 | Olive 5Y 4/4, 5/4 | Silty clay | | Moderate fine prisms separating to weak fine and medium plates and fine angular blocks Very sticky, very plastic | pH 7.4 | Abrupt smooth | Prism faces coated with greenish gray (5BG 5/1). Some very dark gray (N 3/). Stains on ped faces. Sand and pebbles mixed with clay (86-91) |
| | IICR 91+ | | | | | | | Bedrock |
| Spartina alterniflora (high marsh) | A1 0-15 | Dark greenish gray 5GY 4/1 | Silt | | Massive Slightly sticky, plastic | pH 7.3 | Abrupt smooth | Many roots |
| | 15-25 | Dark greenish gray 5GY 4/1 | Silt | | Massive Slightly sticky, plastic | pH 7.6 | Abrupt smooth | Very few roots |
| | IIC2G 25-61 | Dark greenish gray 5GY 4/1 | | | Massive Slightly sticky, plastic | pH 7.7 | Abrupt smooth | Many dead straw colored root fragments. Two 3 cm layers of silt without dead plants |
| | IIIC2G 61-94 | Dark greenish gray 5GY 4/1 | Silt | | Massive Slightly sticky, plastic | pH 7.8 | | Few dead roots |

(Continued)

Table C5 (Concluded)

| Vegetation | Horizon depth (cm) | Color | Texture | Mottles | Structure & Consistency | Reaction | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Spartina patens | A11 0-8 | Dark grey 5Y 4/1 | Silt | | Massive Friable, slightly sticky, plastic | pH 6.8 | Abrupt smooth | About 75% roots by volume |
| | A12 8-15 | Dark grey 10YR 4/1 | Silt | | Massive Friable, slightly sticky, plastic | pH 6.8 | Abrupt smooth | About 95% roots by volume |
| | A13 15-28 | Dark grey 5Y 4/1 | Silt | | Massive Friable, slightly sticky, plastic | pH 6.7 | Abrupt smooth | About 60% roots by volume |
| | C1g 28-61 | Greenish grey 5GY 5/1 | Silt | | Massive Firm, slightly sticky, plastic | pH 7.5 | Abrupt smooth | No live roots, few dead roots |
| | C2g 61-102 | Greenish grey 5GY 5/1 | Silt | | Massive Firm, slightly sticky, plastic | pH 7.0 | | Consists of layers of silt and matted dead very pale brown (10YR 7/4) plant materials. Silt layers are 10-15 cm thick and matted layers 3-5 cm thick |